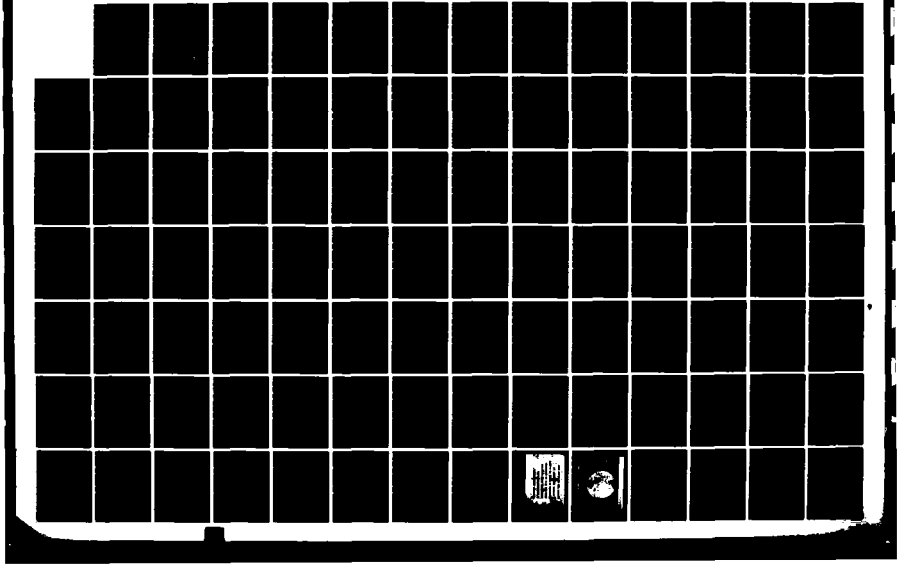
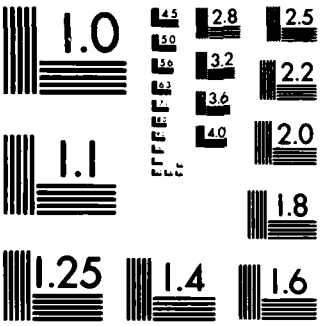
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Kenneth H. Borchers / Joseph L. Hood / Earl H. Langenbeck

Analytical Approaches that Result in Cost Estimating Error Treatment of Cost Estimating Uncertainty: A Reason for Cost Growth
Hank H. Sims

Army Cost Research Program
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Competition in Automotive Commodities: Implications for Competitive and Non-Competitive Acquisition Strategies
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NASA's REDSTAR (REsource Data STorage And Retrieval) Data Base System
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Price Competition Between Major Weapon System Contractors
Dick Trainor

Production Rate Adjustment Factors (PRAF) Cost Model
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Program Management Control System (PMCS)
Hal Henry

Reduce DOD Directives
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Sole Source and Competitive Price Trends in Spare Parts Acquisition
Charles H. Smith / Charles M. Lowe, Jr.

Summary of the Data Problem
Edward P. Laughlin

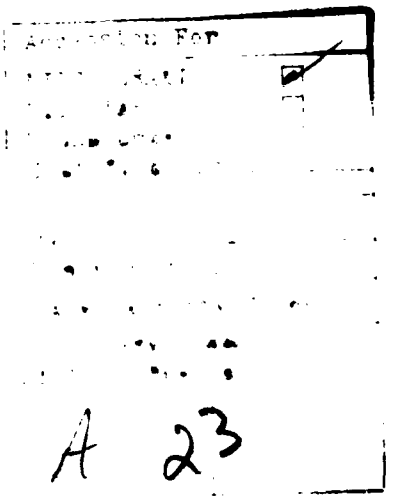
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AD P001223

A CASE HISTORY OF THE COST-BENEFIT ANALYSIS OF A PROPOSED UNIFORM FEDERAL PROCUREMENT SYSTEM

by

Kenneth H. Borchers, Booz, Allen & Hamilton
Joseph L. Hood, Federal Acquisition Institute
Earl H. Langenbeck, Naval Surface Weapons Center

At the request of Congress, the Office of Federal Procurement Policy of the Office of Management and Budget proposed a new uniform federal procurement system (UFPS) designed to improve the efficiency and economy of government procurement and, consequently, government operations. The potential impact of the proposed system could be enormous: federal procurement involves more than $134 billion and 18 million procurement actions each year.

When Congress asked OFPP for this proposal, it also required that the proposal include an estimation of the costs and benefits of the system. The proposal and the cost-benefit analysis was submitted to Congress in February of 1982.[1] Executive Order 12352 issued by President Reagan on 17 March 1982 implemented portions of the proposed system.

[1]For further information see "Proposal for a Uniform Federal Procurement System," and its supplementary volume, "A System Level Cost-Benefit Analysis of the Uniform Federal Procurement System" issued by OMB 26 February 1982.

The Proposed System

The proposed system has seven primary features that were expected to make it superior to the present system (status quo).[2] These features were:

- o improved competition
- o simplification
- o commercialization
- o uniform policy
- o system standards and control
- o integrated management system
- o procurement executive supported by professional workforce.

The proposal also recommended five alternative organizational placements of the improved or enhanced Office of Federal Procurement Policy (OFPP): establishing it as a separate agency; establishing it as a statutory office within OMB; establishing it as a non-statutory office within OMB; establishing it as an office within GSA; establishing it as an office within DOD.

The proposal also considered three options for amending the statutory foundations of federal procurement: maintaining the

[2]Under this system, two major pieces of legislation and approximately 4,500 other laws govern federal procurement.

status quo; enacting a single statute for all procurement; and enacting two conforming statutes -- one for the Department of Defense and one for all other procurements.

The Cost Benefit Analysis

The cost-benefit analysis had to consider what investment would be required to incorporate these features; calculate the cost savings and benefits that might result; and assess how the costs and benefits of the new system compared to the existing system.

It was determined that the nature of the existing and proposed procurement systems precluded the application of a traditional cost-benefit methodology:

- there were no hard data on either the performance of the existing system or the proposed system
- many of the expected benefits and costs were subjective, as were assessments of the existing system
- the time available for completing the analysis was limited.

A two-phase study approach was chosen. A primary analysis established relationships between features of the UFPS. A secondary analysis established a dollar base which was applied to the relationships.

The methodology that was used in the primary analysis was an adaptation of the Analytic Hierarchy Process.[3] The analytical hierarchy process models the tangible and intangible, qualitative and quantitative, and the objective and subjective factors which bear on the costs and benefits of the proposed system. Using this technique, it was possible to develop relationships between cost savings, investments, and benefits.

The secondary analysis was comprised of a literature search to estimate the cost savings associated with features of the proposed system and an analysis of federal contracting practices.

Primary Analysis

The purpose of the primary analysis was to:

- assess the expected investments and savings associated with each management and statutory alternative
- assess the relative importance and contribution of each system feature to the overall costs and benefits of the system
- assess the system alternatives in relation to the present system (status quo).

[3]See Satty, Thomas L., The Analytic Hierarchy Process: Planning, Priority Setting, and Resource Allocation, McGraw Hill, Inc., New York, 1980.

The primary analysis of the UFPS made several assumptions: The present system does not incorporate the features of the proposed system; the time comparison between the two systems is the present and an unknown point in time when the UFPS system is fully operational; the cost of the proposed system represents a reallocation of resources. Because of these assumptions, discounting was not incorporated.

A questionnaire was developed to gather the needed data from 150 expert sources. These sources represented, individually or by affiliation, 95 percent of the organizations and agencies that receive or contract for federal dollars in procurements. They were asked to provide informed judgments about the relationships between features of the system, the management and statutory alternatives, and about the status quo in relation to the investment, cost savings, and benefits associated with each feature and alternative.

For example:

> What is your opinion as to which alternative will provide the greater difference in benefit? improved competition ... or ... system standards and What is the degree of difference?

The 120 surveys completed provided 20,000 judgments comparing 82 alternatives. The responses were subjected to rigorous testing for consistency.

The analysis of this data (the degree of difference) resulted in the determination of the relative contribution of each of the proposed system features to the overall benefits expected to result from the proposed system:

System Feature	Percent of Contribution To Total Benefit
Improved Competition	14
Simplification	20
Commercialization	10
Uniform Policy	15
System Standards	10
Integrated Management System	9
Procurement Executive	22
Total	100

Ratios were developed for comparing each management and statutory alternative to the present system (status quo) in terms of cost savings, benefit, investment, and savings-to-investment.

Savings to Investment Ratios

Statutory Framework	Management Structure	Ratios
Current	Status quo	2.26
Dual	OFPP (statutory)in OMB	1.39
Conforming	OFPP (non-statutory) in OMB	1.13
	OFPP in GSA	.23
	OFPP in DOD	.43
	OFPP as separate agency	1.58
Single	OFPP (statutory) in OMB	3.98
	OFPP (non-statutory) in OMB	3.84
	OFPP in GSA	.77
	OFPP in DOD	1.29
	OFPP as separate agency	.98

The primary analysis provided data that were used in the next stage of the analysis to translate the expected relative costs and benefits of the UFPS features into a total dollar value of the proposed program.

Secondary Analysis

The secondary analysis included a search of literature on procurement to obtain information on the cost savings that could be realized from incorporation of the features of the system and an analysis of federal procurement practices.

The only feature for which sufficient data were available to perform this analysis was "improved competition." The analysis required identifying the federal procurement dollars awarded non-competitively, estimating how many of those dollars could have been awarded under a competitive bidding process, and estimating the savings that could be realized as a result.

A literature search revealed that a range of 20-30 percent of sole-source procurements could be converted to competitive procurement. The cost savings of this conversion was estimated to range from a low of 7 percent of the total contract value to a high of 25 percent.

A conservative estimate of total annual cost savings from improved competition was thus $1.01 billion. An optimistic estimate of annual savings was $5.4 billion.

Range of Cost Savings Resulting From Improved Competition

Non-competitive federal procurement	$72 billion*	
Portion convertable to competitive procurement	Conservative 20%	Optimistic 30%
New competitive federal procurement	$14.4B	$21.6B
Estimate of cost savings from competition		
low - 7%	$ 1.01B	$ 1.51B
high - 25%	$ 3.60B	$ 5.40B

*Source: Federal Procurement Data System, 1981.

The primary analysis determined the proportion of total benefits that would be contributed by each system feature. Consequently, estimating the dollar value of any single feature allowed a value to be estimated for each of the remaining features, and thus, the total program.

The ratios developed during the primary analysis allowed these figures to be converted into a range of dollar savings possible from incorporation of the seven features and showed gross savings of between $2.87 billion and $15.36 billion.

Range of Gross Savings ($B)

System Feature	Contribution To Total Benefits	Estimated Savings Low	Estimated Savings High
Improved Competition	14%	$1.01	$5.40
Simplification	20	1.44	7.71
Uniform Policy	10	.72	3.86
Commercialization	15	1.08	5.79
System Standards	10	.72	3.86
Integrated Management System	9	.65	3.47
Procurement Executive	22	1.59	8.49
Total	100		
Gross Savings (Root Sum Square)*		$2.87	$15.36

*Root sum square was used because the features are interrelated.

The ratios of savings to investment developed during the primary analysis showed a relationship of 2.26:1 between savings and investment for the status quo. To achieve cost savings, therefore, a corresponding investment of between $1.27 billion and $6.81 billion is required. This indicated that the proposed system should produce a net annual savings between $1.60 billion and $8.55 billion.

Range of Savings Resulting from Investments in the UFPS

	Low/Conservative Range	High/Optimistic Range
Gross Savings	$2.87B	$15.36B
Investment Required*	$1.27B	$6.81B
Net Savings	$1.60B	$8.55B

*Savings to investment ratio: 2.26:1

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AD P001224

Hank H. Sims

ANALYTICAL APPROACHES THAT RESULT IN COST ESTIMATING ERROR

ABSTRACT

Cost estimating within the Army has become a specialty with the associated regulatory documents, "How-to-do" guidebooks, and training programs. Within these guidelines, much flexibility is allowed regarding specific analytic techniques used in developing the various cost estimates. Some analytical techniques currently used are not mathematically sound and hence lead to errors in the resulting estimate. This article describes two such techniques with recommended alternative techniques that should produce more accurate estimates. The first technique shows that the simple addition of point estimates may not result in the most likely cost prediction.

TREATMENT OF COST ESTIMATING UNCERTAINTY: A REASON FOR COST GROWTH

Department of the Army guidance for developing Life Cycle Cost Estimates for Weapon Systems is described in a series of pamphlets. These pamphlets, DA Pams 11-2, 3, and 4 describe recommended approaches to developing cost estimates for the Development, Investment, and Operating and Support phase respectively. Paragraph 3-5 is common to all three pamphlets. This paragraph states in part:

> "3-5 Range Versus Point Estimates. a. The use of a point estimate does not reflect the uncertainty associated with the estimate. ...A range of costs should be provided. ...The level at which ranges can be provided is dependent on the level at which costs are estimated. ...Ranges should be presented at the highest aggregate level."

This paragraph goes on to say that a sensitivity analysis should be performed on the impact of requirements, configuration, and program changes. These sensitivity analyses are outside the scope of this discussion and are mentioned only to avoid confusion of a reader attempting to include these sources of uncertainty.

The DA Pamphlets do not prescribe how an analyst is to combine the ranges of estimates from "the level at which costs are estimated" through successive levels to the highest aggregate level. This combining process is the focus of this section.

In reviewing Life Cycle Cost Estimates developed under this guidance, three distinct approaches to this combining process are found. These are:

1. The simple addition of lower level cost estimates and their related low and high (range) estimates.

2. Various simulation techniques of accomplishing this summation.

3. A mathematical technique called "The Symmetric Approximation Technique."

Simulation processes are highly variable. This approach is surely adequate but it requires Operations Research and computer skills and a computer. These resources may not be available. The repetitive calculations of the Symmetric Approximation Technique can be easily programed on most programable calculators.

The Symmetric Approximation Technique is the application of the Central Limit Theorem assuming that we can accurately describe the distribution of individual cost elements and that these distributions are mutually independent.

1. The Central Limit Theorem says, for known (or assumed) distributions, that the sum of several different distributions is a distribution with a mean equal to the sum of the several means and a variance equal to the sum of the several variances. It further states that as the number of individual estimates becomes large, the resulting distribution is normal. The number of distributions summed is considered large if there are 30 or more and normal (Z) statistics are used. For less than 30 distributions, the "t" statistic is used.

2. For practical usage the distribution of individual cost estimates can be assumed to be described by a Beta distribution. This distribution has appealing characteristics, for cost estimating, of finite end points and the ability to handle skewedness (i.e., the lack of symmetry of individual estimates). The parameters of the Beta distribution are very closely approximated by

$$\text{Mean} = \frac{L + 4ML + H}{6}$$

$$\text{Variance} = \frac{H-L}{6}$$

where;

L = Lower bound of the estimate.
ML = Most likely estimate.
H = Higher bound of the estimate.



To illustrate the comparison of these two techniques, three examples are presented.

Example 1 in tabular form, including calculations of distribution parameters, is described below:

Cost Element	Low	Most Likely	High	Mean $\frac{(L+4ML+H)}{6}$	Variance $\frac{(H-L)2}{6}$
1	3	5	12	5.83	2.25
2	4	7	11	7.17	1.36
3	2	4	7	4.17	.69
4	8	9	10	9.00	.11
5	5	8	12	8.17	1.36
6	4	8	12	8.00	1.78
7	5	7	11	7.33	1.00
8	3	5	14	6.17	3.36
9	6	7	10	7.33	.44
Totals	40	60	99	63.17	12.35

With this information, a confidence interval can be constructed on the distribution of totals using the Symmetric Approximation Technique. To define an interval which will include the actual cost with a 98 percent probability, we use a "t" from any probability text with eight degrees of freedom ($t_{(1-\alpha,df)} = t_{(.98,8)} = 2.896$). This interval is:

$$\text{Mean} \pm t \sqrt{\text{Variance}}$$

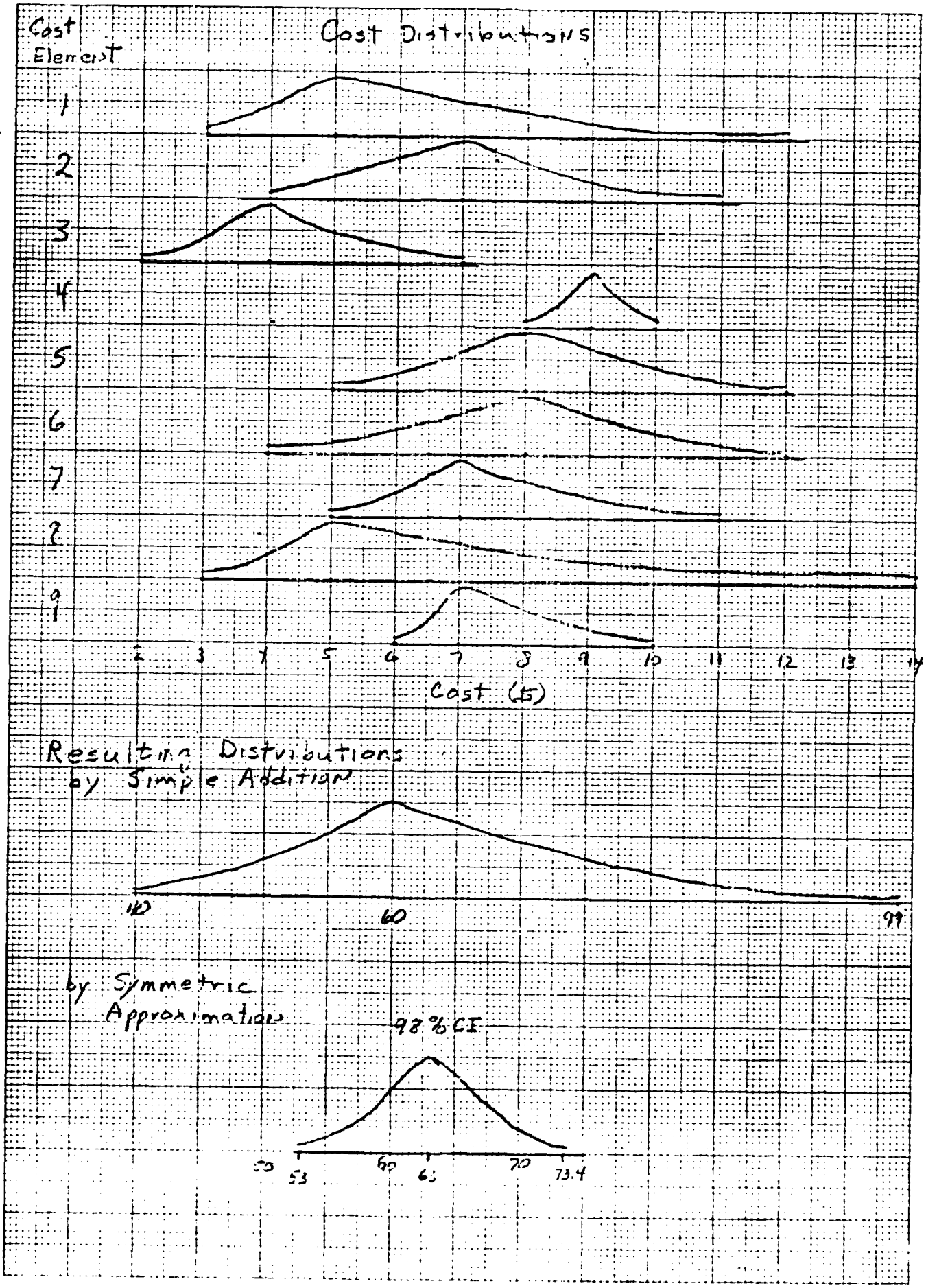
or;

$$63.17 \pm 2.896 \sqrt{12.35}$$

yielding,

$$52.99 \leq 63.17 \leq 73.35$$

These calculations are illustrated pictorially as follows:



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The results of this example are striking. First, in the reduced range of the estimate using the Symmetric Approximation Technique and second, by the shift of the most likely estimate away from the sum of the most likely estimates using the simple addition technique. The mean and most likely (mode) are identical in the resulting normal distribution.

Both of these phenomenon are logical under the Central Limit Theorem.

The reduced range is logical due to the addition of variances instead of standard deviations, or as in the simple addition case, the addition of high and low estimates. This is intuitive since the likelihood of the actual cost drawn from each of the distributions of probable cost being consistently at either the high or low end point is obviously very small. The probability of each actual cost being drawn very near either the high or low end point is very small. Considering all possible combinations of such likelihoods yields the mathematical result described by the Symmetric Appoximation Technique.

The shift in the estimated cost away from the sum of the most likely estimates of the individual estimates derives from the symmetry of the resulting normal distribution under the Symmetric Approximation Technique. The most likely (mode) is equal to the mean in a normal distribution and is determined by summing the means of the individual cost distributions. If the individual cost distributions are consistently skewed toward either high or low, the sum of the means will shift away from the sum of the most likelies, and in the direction of the skewedness.

In cost estimating, it is logical that most cost estimates have greater uncertainty to the high side hence the means of the individual cost distributions are generally to the right of the most likely estimates. This means that most cost estimates are low if they are based on the summation of the most likely costs of the components of the system. Further, this is true whether cost estimating ranges are considered or not. Simply not considering cost estimating uncertainty does not eliminate its impact. This means that even a point estimate of total derived by adding point estimates of contributing cost elements is likely to be in error.

If it is now established that the character (skewedness and range) of cost estimating uncertainty has an impact upon the resulting estimate itself, the next question is "How great is this impact?"

The first example, with no unusual skewedness experienced a shift of:

$$\frac{\text{Sum of Means-Sum of Most Likelies}}{\text{(Sum of Most Likelies)}} \times 100 =$$

$$\frac{63.17-60}{60} \times 100 = 5.3\%$$

If there is considerable high side uncertainty or if there is a larger number of individual estimates being summed, the significance of this shift increases.

Consider, for illustrative purposes, nine identically distributed cost elements with low, most likely, and high estimates of 100, 110, and 200 respectively. This yields for the simple addition technique the sums of; low=900, Most Likelies=990, and Highs=1,800, and for the Symmetric Approximation Technique the sums of; Means=1,110 and Variances=2,500. Using a 95 percent confidence interval ($t_{(95,8)} = 2.306$) this yields:

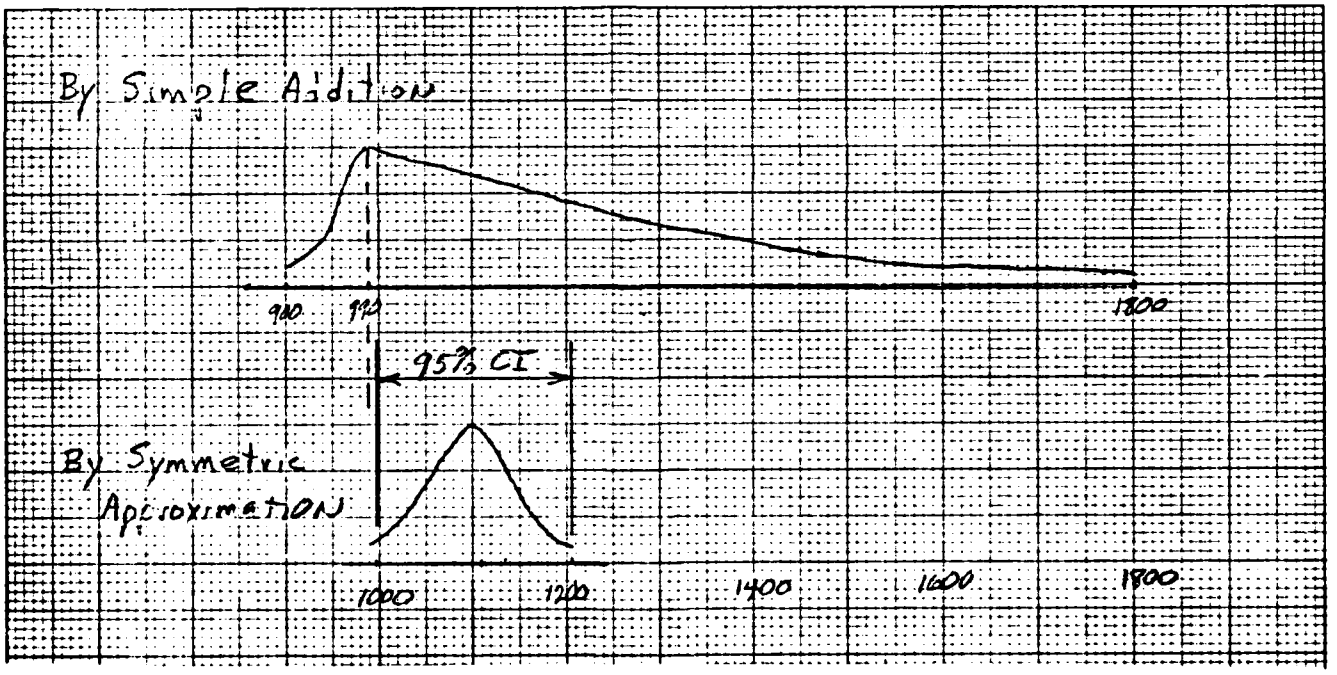
$$\text{Mean} \pm t\sqrt{\text{Variance}}$$

$$1{,}110 \pm 2.306\sqrt{2{,}500}$$

or;

$$995 \leq 1{,}100 \leq 1{,}225$$

or pictorially;



The sum of the most likely estimates is not even within the 95 percent confidence interval. Or, stated differently, based on the sum of the most likely estimates there is a 97.5 percent chance of cost overrun. This overrun is expected to be;

$$\frac{1,110 - 990}{990} \times 100 = 12.1\%$$

To illustrate the impact of more numerous individual estimates, consider another example, a Consider 31 identically distributed cost elements with low, most likely, and high estimates of 500, 600, and 800. This example yields the sums of: Lows=15,500, Most Likelies=18,600, Highs=24,800, Means=19,117, and Variances=77,500. This yields a 90 percent confidence interval of;

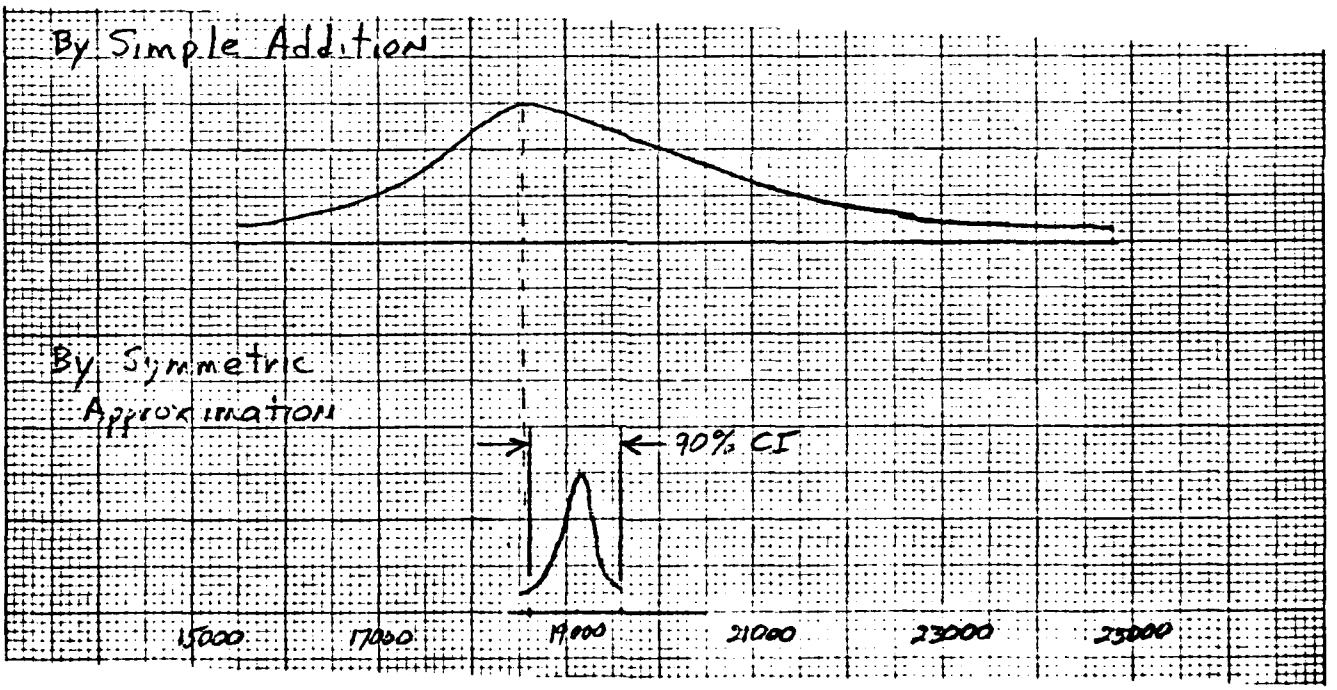
$$\text{Mean} \pm Z_{(90)} \sqrt{\text{Variance}}$$

$$19,117 \pm 1.645 \sqrt{77,500}$$

or;

$$18,659 \leq 19,117 \leq 19,575$$

or pictorially;



FP1 10M 20 X 20 TO 1 INCH
5TH, 10TH AND 20TH LINE PROGRESSIVELY ACCENTED

Here there is a 95 percent chance of a cost overrun. This overrun has an expected value of $\frac{19,117-18,600}{18,600} = 2.8\%$

This example illustrates the shift in the basic cost estimate and also shows the significance of the reduced range of cost estimating uncertainty with the increased number of individual estimates.

The three examples shown illustrate definite impacts on both the value of the resulting cost estimate and the uncertainty range about that cost estimate. These impacts result only from the method of summing cost estimating uncertainty. The numerical value of this impact is highly variable considering the size of the uncertainty, and the degree of skewedness of this uncertainty for the individual cost elements and the number of cost elements considered.

Examples can readily be constructed that show an expected cost overrun of 25 percent or even 50 percent when both skewedness and the number of individual estimates are increased. This impact is potentially very serious but most significantly, this impact is generally not evaluated.

Note: This article describes a practical approach to cost estimation when limited data is available. There are two areas included here that may be of concern to mathematicians. They are the facts that the individual distributions are assumed to be accurate (i.e., population estimates) and that these individual distributions are independent, one from another.

1. If adequate data is available to develop sampling distributions for each individual cost estimate, the sample mean and variance can be used without altering the basic approach discussed.

2. The independence of individual cost estimates should be treated carefully. If two or more individual estimates are dependent both in "location" and "dispersion", these estimates should be combined prior to applying the techniques discussed in this article. Conversely, if there is no rationale that the specific value of a random variable drawn from one distribution dictates or strongly influences the specific value of the random variable that will be drawn from another distribution, these distributions can be reasonably assumed to be independent. It is important to note that all simulation approaches to combining cost estimating uncertainty suffer equally with the Symmetric Approximation technique in this difficulty.

[1]"Statistical Methods of Measuring the Uncertainty of Cost Estimates", E. L. Murphy, US Army Missile Command, 26 Feb 70.

[2]"Coming to Grips with Cost Estimating Uncertainty," CPT D. Carraway, HQ, USADARCOM, 23 Oct 80.

Statistical Models in Engineering, Hahn and Shapiro, John Wiley & Sons, New York, 1967.

Quantitative Approaches to Management, Levin and Kirkpatrick, McGraw Hill, New York 1971.

MULTIPLE RANGE ESTIMATING TECHNIQUE

The second area of concern regarding the interaction of uncertainty is the treatment of the uncertainty inherent in an estimate that is derived as a function of another estimate. This is of concern where there is uncertainty in both the basic estimate and in the relation of this estimate to the derived estimate (factor).

Typically, this situation is handled by multiplying the lower, most likely, and high estimates of the basic estimate by the low, most likely, and high estimates respectively of the factor. The resultant values are considered to be the low, most likely, and high estimates of the derived estimate. The best approach to illustrating this is through an example.

Consider the requirement to build a factory. It is estimated that 50,000 square feet of floor space is required plus or minus 15 percent (requirements uncertainty). The current cost of construction is $50 per square foot $\pm$ 20 percent (cost estimating uncertainty) depending on the characteristics of the construction and the state of the economy. This translates into a square foot requirement L=42,500, ML=50,000, H=57,500 and a cost per square foot of L=$50, ML=$50, H=$60. What is the expected cost and the related range of uncertainty?

The typical method of constructing this estimate is to multiply the low requirement by the low cost, the most likely requirement by the most likely cost, and the high requirement by the high cost as shown below:

Low Cost = 42,500 ft^2 X $40/$ft^2$ = $1,700,000

Most Likely Cost = 50,000 ft^2 X 50/ft^2 = $2,500,000

High Cost = 57,500 ft^2 X $60/$ft^2$ = $3,450,000

In doing this, we have lost track of the probability of incurring the cost, if, in fact, we had ever considered that probability.

The Multiple Range Estimating Technique approaches this problem differently. Consider that both the requirement and cost distributions have been carefully derived, and the estimated distributions are symmetrical with central tendency such that normality can be reasonably assumed. Further consider that the high and low estimates are derived such that there is less than one percent chance of the true value exceeding either of these limits. Due to the symmetry of the estimates, the means of the assumed normal distributions are equal to the most likely estimates.

Now to determine the distribution of total cost with consideration of both requirements uncertainty and cost estimating uncertainty. If we multiply the high limit of requirements uncertainty by the high limit of cost estimating uncertainty, we get:

$57,500 \text{ ft}^2 \times \$60/\text{ft}^2 = \$3,450,000$

This is the same value as determined by the typical approach. But what is the probability of experiencing this cost?

If the probability of meeting or exceeding 57,000 ft^2 is one percent and the probability of meeting or exceeding $\$60/\text{ft}^2$ is one percent, the probability of meeting or exceeding both is one percent X one percent = .01 percent. This means that the range described is too broad to be consistent with other estimates being provided at the 99 percent level.

If the 90 percent limits for both distributors were identified, the probability of meeting or exceeding both upper limits would be 10 percent X 10 percent = 1 percent. This would be consistent. This is the key to the Multiple Range Estimating technique. For our example, this is accomplished as follows:

Since it is assumed that no more than one percent probability exists that the true value will exceed the high requirements and cost values, the standard deviation of these distributions can be calculated. The 99 percent upper limit of the normal distribution is:

$$\text{Mean} + Z_{99}\ \text{S.D.} = \text{upper 99\% limit}$$

or;

$$\text{Mean} + 2.326\ (\text{S.D.}) = \text{upper 99\% limit, and}$$

$$\text{S.D.} = \frac{\text{upper 99\% limit} - \text{Mean}}{2.326}$$

For the floor space requirement, this is:

$$\text{S.D.} = \frac{57,500 - 50,000}{2.326} = 3,224 \text{ feet}^2$$

and for the construction cost, it is

$$\text{S.D.} = \frac{60 - 50}{2.326} = \$4.3/\text{feet}^2$$

Now, to calculate the upper 90 percent limits for both, we use the normal statistic Z_{90}=1.283. The upper limits are

For requirements:

$$\text{Mean} + Z_{90}\ \text{S.D.} = 50,000 + 1.283\ (3224) = 54,136 \text{ ft}^2$$

and for cost

$$\text{Mean} + Z_{90}\ \text{S.D.} = 50 + 1.283\ (4.3) = \$55.5/\text{ft}^2$$

Now the product of these two values (54,136 ft^2 X $\$55.5/\text{ft}^2$ = \$3,005,485) is the upper 99 percent limit of the assumed normal distributions of cost and requirements uncertainty.

To establish the lower 99 percent limit, the same approach is used but on the lower limits of the uncertainty distribution.

For requirements:

$$50{,}000 - 1.283\ (3224) = 45{,}863\ \text{ft}^2$$

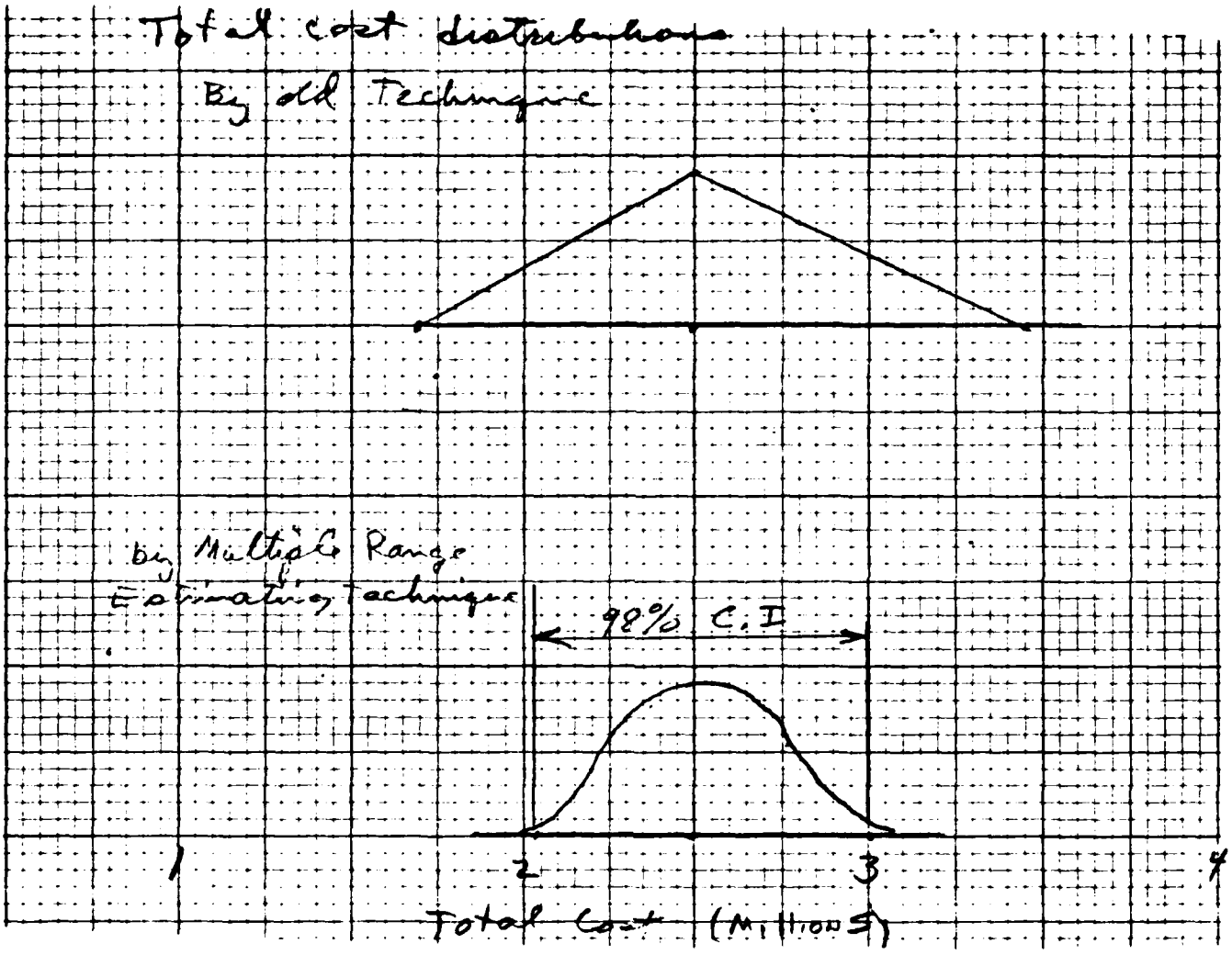
For Cost

$$50 - 1.283\ (4.3) = 44.5\ \$/\text{ft}^2$$

and the lower limit considering both requirements and cost uncertainty is 45,863 ft^2 X $\$44.5/\text{ft}^2$ = \$2,040,156.

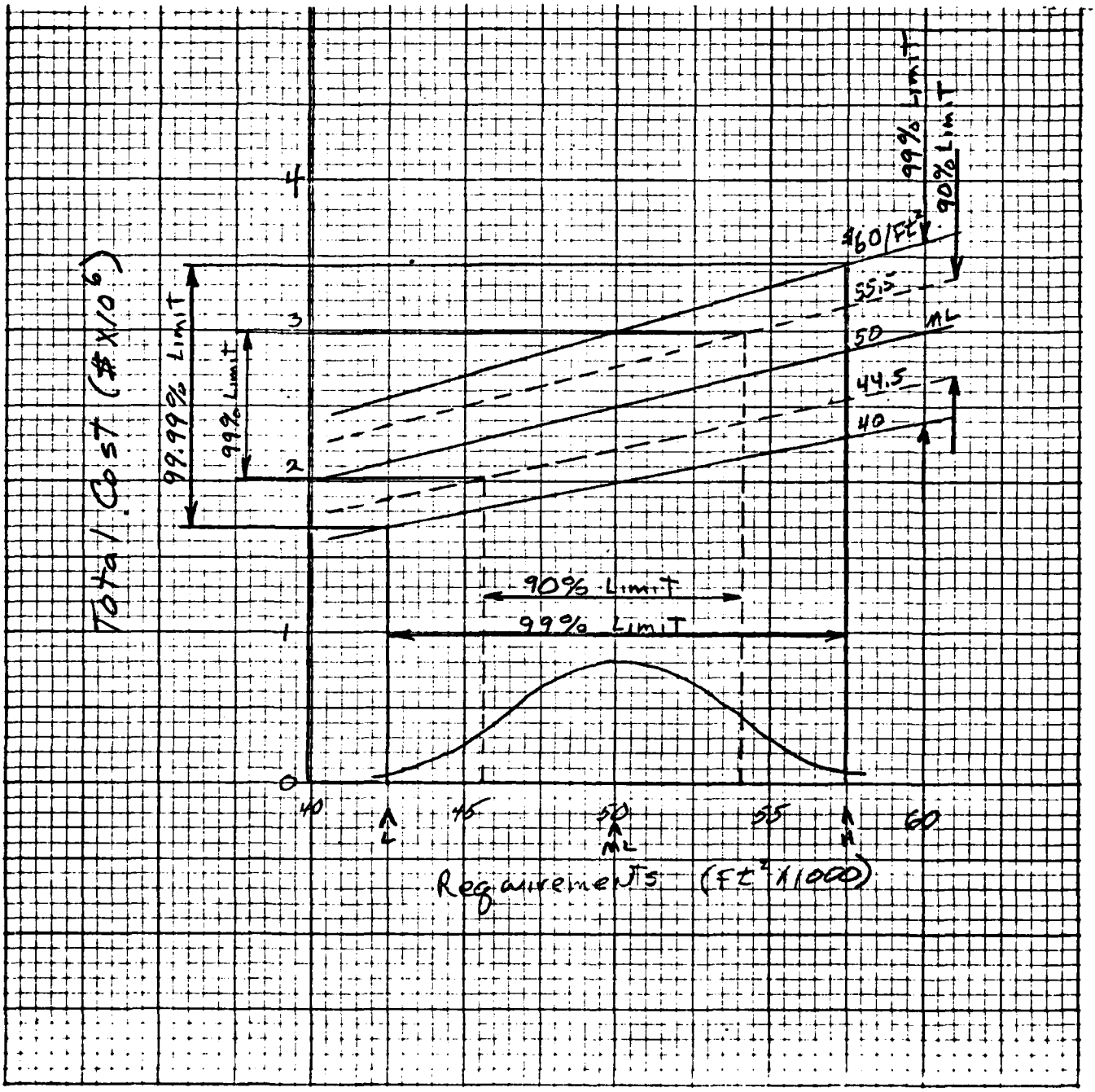
Since the assumed normal distributions are symmetrical, the mean and most likely values are equal 50,000 ft^2 X $\$50/\text{ft}^2$ = \$2,500,000.

The two techniques are compared below.



While the above example results in a 98 percent two-tailed confidence interval, the Multiple Range Estimating Technique is equally applicable for any other confidence level; the only requirement is that the confidence level of the uncertainties used to develop the total cost uncertainty must be related such that the probability of exceeding each, multiplied together, equals the desired significance level.

Another approach to viewing this technique is to consider a regression analysis for simplicity consider the same example.



Note that this technique is equally applicable when the regression lines are developed analytically and with the characteristically curved "confidence" or "prediction" intervals developed using regression techniques.

The basic Multiple Range Estimating Technique is equally applicable regardless of how the means and Standard Deviations of the input uncertainty distributions are derived. If these uncertainties are derived parametrically, the means and Standard Deviation are known. If uncertainties are using expert opinion in obtaining high, low, and most likely estimates, the Beta Distribution might be assumed for derivation of these means and Standard Deviations. If these uncertainties are derived statistically from a sample of less than 30 elements, the "t" statistic can be used.

The next step is to develop a table of squares or square roots of the normal table to allow convenient use of this technique at any level of significance.

The calculations required are not difficult and are easily programed on any programable desk calculator if repeated applications are planned.

THE AUTHOR

Mr. Charles H. Sims is a native of Trimble, Missouri. His educational background includes a Bachelors Degree in Mechanical Engineering in 1965 from the University of Missouri and a Masters Degree in Industrial Engineering/ Operations Research in 1968 from Texas A&M University. Mr. Sims served as an instructor at the US Army Logistics Management Center, 1970-1975, where he developed and directed the Cost Estimating for Engineers Course. He served as Director, USAREUR Resource Management School, 1975-1977, and is currently serving as an Operations Research Analyst at the US Army Logistics Center. His current position involves developing Economic Analyses of Management Information Systems and Life Cycle Cost Analyses for Computer Hardware Systems. His experience in teaching Cost Estimating Theory and Practices and then applying those theories lead him to the conclusions presented in this article.

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AD P001225

(23)

ARMY COST RESEARCH PROGRAM

COST RESEARCH

(CDAC)

COST DISCIPLINE ADVISORY COMMITTEE OBSERVATIONS :

NO SINGLE ARMY-WIDE PLAN EXISTS FOR COST DATA AND METHODOLOGY IMPROVEMENTS

NO CONTRACTOR SUPPORT IS PROVIDED FOR COST ANALYSIS RESEARCH .

CDAC RECOMMENDATION :

ARMY-WIDE PROGRAM TO UPGRADE COST ESTIMATING METHODOLOGY BY ACTIVE CONTRACT RESEARCH PROGRAM .

DA/DARCOM ACTIONS

- ESTABLISH A COST RESEARCH PLANNING BOARD
- ESTABLISH THE STRATEGY
- BUDGET AND PROGRAM FOR RESEARCH
  - -- HQDA
  - -- HQ, DARCOM
- DEVELOP AN ANNUAL PLAN
  - -- CONTRACT
  - -- IN-HOUSE

ARMY OVERVIEW

ARMY ROLE AND STATUS

- COST RESEARCH PLANNING BOARD ESTABLISHED
- BOARD MEMBERSHIP
  - -- DCA, CHAIRMAN
  - -- DAB
  - -- DPAE
  - -- ASA (IL&FM)
  - -- DARCOM
  - -- TRADOC
  - -- FORSCOM
  - -- USAREUR
  - -- ACC
  - -- CAA
- INITIAL MEETINGS REVIEWED
  - -- CHARTER
  - -- GOALS
  - -- RESPONSIBILITIES
  - -- ARMY PLAN
  - -- FY83 MACOM PROJECTS
- NEXT MEETING 1 SEPT 1982
  - -- PRIORITIZE FY83 PROJECTS
- FY83 ARMY-WIDE COST RESEARCH PLAN PUBLISHED
  - -- OCTOBER 1982

WHERE WE ARE

DARCOM ROLE AND STATUS

- MEMBER OF ARMY COST RESEARCH PLANNING BOARD
- GENERAL DARCOM STRATEGY ESTABLISHED
- CONTRACT ALTERNATIVES EXAMINED
- PRIORITIES DETERMINED
- FY82 PROJECTS IDENTIFIED AND CONTRACT PROCEDURES INITIATED
- FY83 PROJECTS IDENTIFIED FOR CONSIDERATION

DARCOM COST RESEARCH STRATEGY

GENERAL AREAS OF RESEARCH

- ESTABLISHMENT OF R&D AND INVESTMENT COST DATA BASES AND COST ESTIMATING METHODOLOGY FOR AIRCRAFT, MISSILE, TRACK AND WHEEL VEHICLE, ARMAMENT, OR ELECTRONIC SYSTEMS.

- ANALYSIS OF THE IMPACT OF TECHNOLOGICAL ADVANCES ON WEAPON SYSTEM R&D AND PRODUCTION COST ESTIMATION.

- DEVELOPMENT OF AUTOMATED DATA SYSTEMS AND MODELS IN SUPPORT OF WEAPON SYSTEM LIFE CYCLE COST ESTIMATION.

- ANALYSIS OF THE UTILITY OF DATA FROM EXISTING DOD COST REPORTING SYSTEMS FOR NEW SYSTEM COST ESTIMATION.

- EMBEDDED COMPUTER SOFTWARE INVESTMENT AND O&S COST ESTIMATION.

- INTEGRATED LOGISTIC SUPPORT COST ESTIMATION.

- ANALYSIS OF THE FACTORS WHICH INFLUENCE UNIT PRODUCTION COST.

DARCOM FY82 ACTION PLAN

PROJECTS TO BE INITIATED DURING JUL-SEP 1982

- MISSILE DATA BASE: DARCOM CONTRACT...5 M/Y OF EFFORT
  - -- CURRENT COST ELEMENTS
  - -- COST OF NEW TECHNOLOGY
  - -- NEW COST ESTIMATING RELATIONSHIPS
- COMMUNICATIONS DATA BASE: DA CONTRACT...5 M/Y OF EFFORT
- ASSESSMENT OF DARCOM COST MODELS: HQ, DARCOM, IN -HOUSE
  - -- REVIEW EXISTING MODELS FOR CONSISTENCY

FY83: CANDIDATE RESEARCH PROJECTS

- DATA BASE IMPROVEMENTS
  - -- WEAPONS
  - -- TRACKED VEHICLES
  - -- ARMAMENT
  - -- AIRCRAFT
- METHODOLOGY TO PREDICT FIRST UNIT PRODUCTION COST FROM PROTOTYPE COST
- IMPROVE LIFE CYCLE COST TRACKING AND ANALYSIS PROCEDURES
- EXPAND AUTOMATION OF IPCE/BCE MODELS
- METHODOLOGY TO ASSESS ILS IMPACT ON COSTS

BEYOND FY83: CONCEPT

- CHECK AND ADJUST PROGRAM AGAINST STATED GOALS

AD P001226

20

Competition in Automotive Commodities: Implications for Competitive and Non-Competitive Acquisition Strategies

by

Patrick N. Watkins

Contract Price Analyst

U.S. Army Tank-Automotive Command

During the 1970's, several research organizations undertook rigorous studies of the effects of competition on weapon system cost. The basic goal of these investigations was to determine the net cost savings attributable to competition. As various problems in methodology were solved, a model was evolved which could be used to predict the probable effect of competition on an individual system. The model is used in conjunction with a database of competitive and comparable sole source acquisition histories. The purpose of this paper is to present available data on competition of automotive commodities and to suggest some additional uses for the model in program management and contract negotiations.

THE MODEL

Initial attempts to analyze competitive savings relied on the use of simple arithmetic. Program acquisition histories were examined. Study candidates consisted of items where a sole source buy was followed by a competitive one. Savings were the difference in the two unit recurring prices after adjusting for inflation to a uniform base period. This approach was not ideal, as it ignored probable price decreases from sole

source "learning." Researchers then attempted to project the sole source price improvement curves (with varying success) over the competitive quantities. Savings were then calculated by taking the difference in prices between the projected sole source prices and actual competitive prices.

Researchers soon realized that this approach could be improved and extended. A model was then developed with which to predict the results of competition for a given system. The model requires a projection of sole source prices in constant year dollars over the competitive period, a similar projection of prices under competition, and an assessment of costs other than unit recurring costs. Generally speaking, it is the projection of economic behavior under competition that requires the most judgement. Usually, a sole source baseline is available either from the program Baseline Cost Estimate or contractor data. Nonrecurring costs are normally assessed directly with experts-estimating facilities costs, testing, machinery requirements, administrative costs, and other costs. The projection of competitive savings (or loss) must be made with little, if any data, on potential cost behavior for competitors. It must be made primarily by comparison with the available database of competitive cases.

The model requires inputs on price improvement curve variations from the projected sole source case. Two possible movements exist, curve shifts or curve rotations. Combinations may occur. Shifts are easier to handle, as a fixed percentage change is applied to the sole source projection at one or more points on the curve. Shifts are also intuitively easier for the layperson to understand. Some evidence exists that both may occur.

THE COMPETITIVE DATABASE

While several studies have been conducted on the subject, The Institute for Defense Analysis (1) and The Analytical Sciences Corporation (2) compiled the most comprehensive lists of the available data to date. The emphasis in these studies was not on commodity classes. All competitive cases are analyzed collectively, although some segregation was made for various segments of the studies. I have regrouped the data and some of the findings into commodity groups in Table 1.

In early 1982, a team was convened to assess the potential effects of competition on the Bradley Fighting Vehicle Systems. The study was conducted for the Army Material Development and Readiness Command (DARCOM) and was chaired by Mr. Robert F. Williams of the Army Procurement Research Office. One of the problems encountered by the team was that no commodities in the existing database resembled the Bradley systems. As part of the study, a search of contract and other procurement files was conducted to develop data on automotive competition. Data was also solicited from the Armaments Command (ARRCOM), and the Naval Sea Systems Command.

THE AUTOMOTIVE DATABASE

Acquisition pricing histories were collected from TACOM files, Should Cost Study Documents, and from conversations with ARRCOM and Navy personnel. The search uncovered four vehicle families encompassing 12 vehicles for which sufficient data existed to make comparisons. Of these, six were sole source throughout the acquisition life cycle and six had been competed at one time or another. No cases had a sole source period followed by a

TABLE 1

THE COMPETITIVE DATABASE

Commodity	(Source)	Cases	Rotation	Shift (Range)
Electronics	(1)	30	N/A	35.6% (-16.1%, 67.7%)
	(2)	17	N/A	48.0%
Missiles	(1)	10	N/A	25.6% (- 5.6%, 59.2%)
	(2)	9	N/A	17.0%
	(1)	4	3.9% $\pm$ 2.0%	N/A
Munitions	(1)	5	N/A	31.0% (- 4.5%, 61.2%)
	(2)	2	N/A	17.0%
Bombers	(1)	4	4.4% $\pm$ 2.1%	N/A
Aircraft Components	(2)	3	N/A	41.0%

competitive period from which meaningful conclusions could be drawn. Since the team disbanded, three more cases have been discovered, and are presented here for the first time. The case histories indicate three conclusions. Automotive commodities have unique characteristics. Competition can generate savings even when the incumbent producer never looses. And, post award claims may be a significant risk of competition. Table 2 summarizes the accumulated data. All prices are adjusted to December 1980 dollars. The Appendix contains the table of inflation adjustment factors used and the actual data. The factor was developed using the Producer Price Index for Industrial Commodities and Compensation per Hour, Manufacturers, weighted .8 and .2, respectively. This mix is representative of the actual cost mix for the systems for which cost data were available. Compensation per Hour includes certain fringe benefits which more accurately reflects labor costs. Data Resources projections were used for the period 1982-1985. As precise delivery periods are unknown in most cases, the factor application is somewhat imprecise. Leadtime of approximately 18 months is assumed. Final contract prices are available only for the M113. All others are award prices.

M113 FAMILY

The base vehicle for the family is the M113 Armored Personnel Carrier. On the same basic chassis, the following derivative vehicles are built: M577 Command Post, M548 Cargo Carrier, M125 Mortar, and M106 Mortar. The M113 has been produced continuously since 1959 by FMC Corporation. The derivative vehicles were introduced at several points in time since then. The power train and armaments have always been

Government furnished. Other minor hang-on items are also furnished. In 1964, the M113A1 configuration was introduced with no significant effect on program cost. In 1979, the M113A2 configuration was introduced with significant changes to the vehicle. It was, therefore. excluded from study.

M113 APC

The M113 was competed almost every other year from 1960-1969. All competitions were winner-take-all, and most were conducted by means of formal advertising. Two multi-year contracts were awarded as a result of competitions in 1965 and 1969. One sole source multi-year contract was awarded in 1967. The system reverted to sole source production in 1971.

The 1959 acquisitions were included in the competitive period, even though the awards were sole source. The Army had clearly intended to compete the follow-on contracts which put obvious price pressure on the incumbent. Results do not differ when the 1959 buys are excluded from the competitive period. Through 1970, approximately 28,000 M113's were bought. Prices followed a consistent 91% price improvement curve throughout the period. No significant differences could be detected between the behavior of the incumbent on sole source buys and the intermixed competitive buys. Curve slopes do not vary significantly from the composite 91% curve. Several hundred engineering changes were generated under the 1965 multi-year, resulting in price increases. When the award prices are used for that contract, a slightly steeper 90% curve fits the data. However, the incumbent may have bought-in and used the changes to recover to his appropriate cost curve.

TABLE 2

THE AUTOMOTIVE DATABASE

Vehicle	Curve Slope		Contract-To-Contract Shifts		
	Sole Source	Competitive	Competitive	Sole Source	Should Cost
M113	100%	91%		(7.0%)	4.0%
M548	100%			(9.0%)	5.0%
M577	100%		12%	(7.0%)	8.0%
M125	100%		16%	(15.0%)	5.0%
M106	100%		14%	(41.0%)	12.0%
M60			31%		(10.0%)
M60A1	100%			(5.0%)	
M38		98%		0.6%	
M38A1	98%				
M109A1B	95%			(3.0%)	
M109A2	100%			(1.0%)	
M110	100%			(5.0%)	
M578	100%			(6.0%)	
M320RT		93%		(55.0%)	
T-3			30%		
Wheel APC			13%		
Average	100%	94%	19%	13.0%	4.0%
Range	95%, 100%	91%, 98%	31%, 12%	0.6%, (55%)	12.0%, (10%)

All shifts are savings, except parentheses indicate increases.

This cost behavior contrasts sharply with the sole source period 1971-1978. The period is characterized by constant-dollar price increases which are only ameliorated by Should Cost Studies. The very first sole source acquisition in 1971 exhibited a 13% increase in constant dollar price. Average increases were 7%. Should Costs obtained reductions of 4%. For the period as a whole, the acquisitions subjected to Should Costs averaged 12% higher prices than the competitive period and the remainder averaged 19% higher prices than the competitive period.

M548 Cargo Carrier

The M548 was competed for the first production buy only. The only significant price improvements result from Should Costs. Average price increases were about 9%. Should Costs achieved average reductions of about 5% in constant dollar prices.

M577 Command Post

The M577 was competed three times, on the initial production buy and two non-consecutive follow-on contracts. Reductions were 10% and 15% in constant dollar prices. Should Costs obtained reductions of 8% on average. Sole source buys produced average constant dollar price increases of 7%. A substantial improvement occured in 1969 on a sole source buy. It may be attributable to tripling of quantity from 205 to 662. The improvement was not sustained when quantity reverted to the 200 level. When that contract is excluded, the sole source buys exhibited constant dollar price increases averaging 11%.

M125 Mortar

The M125 was competed once after initial production, which resulted in a 16% reduction from prior sole source constant dollar prices. Should Costs obtained improvements averaging 5%, even over very small quantities. Remaining sole source prices increased an average of 15%.

M106 Mortar

The M106 was competed twice after initial production, with 18% and 10% reductions. Two Should Costs obtained 12% improvements. Four remaining buys produced 41% increases in constant dollar prices.

M88 Recovery Vehicle

The M88 was produced in two versions, the M88 from 1960-1962, and the M88A1 from 1976 to present. The A1 configuration includes many power train and suspension improvements which precluded comparison of the two periods. Bowen-McLaughlin-York produced all vehicles, 1,052 M88's and 970 M88A1's through FY1980. The M88 was competed twice with a sole source contract sandwiched between the two. The 1960 contract was competed together with the M60 Tank, but the two vehicles were awarded to separate contractors. The 1961 contract was awarded sole source at a 0.6% price reduction. The 1962 contract was competed with a 6% price reduction. A 98% price improvement curve fits the data, but the fit is not good. All M88A1 contracts were awarded sole source. A 98% curve also fits the M88A1 data, and again the fit is not good. All improvements occured in 1979 and were accompanied by

a surge in M88 conversion kit production. No other price improvements were observed.

M60 Tank

The M60 was produced by Chrysler Corporation in four configurations: the M60, M60A1, M60A2, and M60A3. Pricing data are incomplete. Substantial data exist for the M60 and M60A1. The data for the M60A2 is not good enough to reconstruct a history. The M60A3 has only been in production for three buys and sufficient data is not yet available.

M60

The M60 configuration was produced from 1959-1963. Initial award was made sole source on an emergency basis, while a competitive solicitation was being prepared. In 1960, a competition was held for both the M60 and its recover vehicle, the M88. Final award was made to two different firms. Competition reduced constant dollar prices by 31%. No data are available for the 1961-1963 buys.

M60A1

The M60A1 was produced intermittently from 1962-1966, 1968-1972, and 1974-1979. In 1977, significant changes in the fire control subsystem, breakout of track, and improvements in the on-board computer were made. Prices are not comparable to other periods and were excluded from study.

The period from 1964-1976, for which data was available, exhibited steadily rising constant dollar prices, even though the vehicle configuration was relatively stable. One major 14% price improvement occurs in 1974. In that year, production increases from 120/year to 480/year during initial facilitization for the M60 Acceleration Program. Facilitization costs are separate from production contract costs. In 1975, the rate increase from 380 to 1,200 per year resulted in a 13% price increase. Non-Should Cost prices increased 5%, while Should Cost increases were about 10%, but were conducted in unusual circumstances. The FY1972 Should Cost encountered very low rate production (120/year), and the FY1975 problems are noted above.

Self-Propelled Artillery Family

All vehicles in this family were awarded on sole source contracts to the same firm. The M109 has been produced in several versions. Data is available for the M109A1B and the M109A2. The M110 was produced in two configurations, the A1 and A2. The M578 is the remaining member. Only the M109A1B shows any consistent price improvements, and then only over a portion of the acquisition life cycle. From 1972-1974, a 95% curve fits the data. The 1976-1980 period shows constant dollar price increases. The remaining vehicles also show constant dollar price increases. Note that the M578 appears to exhibit price improvements in the period 1978-1980, but production rate is very low, and the price changes may be due to quantity variation. The prices are still over 20% higher than the initial purchase.

M320RT Rough Terrain Crane

The M320RT is a military design crane used primarily for material handling in field operations. It consists of a commercial upper works mounted on a military design crane. Prototypes were built by Le Tourneau in 1957, and Clark Equipment in 1962. Initial production competition was held in 1964 and won by American Hoist and Derrick. A follow-on sole source contract was awarded at a 55% increase in constant dollar prices. The practice on the initial contract was to have an engineer in the contractor's plant who approved engineering changes and few records were kept. Therefore, it is impossible to know what part of the increase is attributable to the engineering changes. The third production contract was competed, and won by the incumbent. Significant engineering changes were included. The follow-on fourth contract was also competed again with engineering changes. This time Harnischfeger Corporation won. A 94% curve fits the second through fourth contracts. However, claims were submitted on the third and fourth contracts, only one of which has been settled. It is not likely that the final contract prices would exhibit constant dollar price increases, although the possibility exists.

Wheeled APC's

The Army recently conducted a competition for domestic requirements for wheeled armor personnel carrier's, which are of privately developed design. No detail will be presented here as these firm's prefer to hold their pricing information confidentially. However, a savings of 13% in

constant dollar terms were realized over prices on FMS contracts.

T-3 Airborne Bulldozer

Recently, the Army purchased a small quantity of modified commercial bulldozers. The modifications were primarily to meet transportability requirements. The acquisition was first approached as a sole source negotiation. These negotiations were terminated prior to agreement by a decision to compete the item. Two-step formal advertising was used and savings of about 30% over the sole source contractor's price were obtained. John Deere bid $38,079, and Caterpillar bid $53,616 per unit.

Other Vehicles

Several other vehicle competitions were examined, but only data on one buy, usually multi-year, was available. These included the Navy LVTP7 and LVTP7A1. Amphibious Assault Vehicles, the M561 Gamma Goat, a military design truck, the Goer Family of Vehicles, and other military design trucks. Two experienced post-award claims in the $5 million (Dec 80 $) range.

INFERENCES

While direct assessment of individual cases examined in isolation will not give much data on inputs for the predictive model, the cases taken together can shed some light. The competitive cases exhibited significant savings over sole source case. Price improvement curves had slopes ranging from 91% to 98%. Isolated competitions generated one time savings

averaging 19% in a range from 12% to 31%. Sole source cases generated price improvement curves from 95% to 100% and above. At most, three of the cases, M88A1, M109A1B, and M578, fall in that range. The remaining nine sole source cases produced constant dollar changes in the range from .6% savings to 55% increase per year. The M113 illustrates reversion to sole source production. Competition generated a 91% price improvement curve, followed by sole source increases averaging 7% per year.

Should Cost Studies were first conducted in the 1970's. Therefore, the effect of conducting Should Cost Studies throughout the acquisition cycle for a production item is unknown. On the M113, constant dollar price reductions for Should Costs were 4% to 12%. On the M60A1, large increases occured, due to unique circumstances. Overall, Should Costs averaged 4% annual reductions. Should Costs would appear to be an attractive management tool for sole source programs, at least among automotive commodities.

Automotive commodities appear to have rather shallow curves in comparison with other commodities. While three cases of sole source constant dollar price increases were observed in other commodities, typical sole source curves were in the 80% - 90% range. (1,2) Bomber cases exhibited curves in the 70% range, as did some of the competitive cases from electronics and missiles. Typically, an automotive manufacturer's "value-added" tends to small, sometimes less than 20% of unit price. With less of the total cost under the prime contractor's control, there is less opportunity to actively generate cost reductions. However, the competitive automotive cases clearly demonstrate that systematic cost reductions, after adjustments for inflation, are possible, and should be expected.

Automotive commodities exhibit no consistent response to production rate variation. Visual inspection of the case histories clearly indicates approximately equal numbers of instances where prices moved in the same direction as production rate, rather in opposite directions. An obvious example is the M60A1, where a tripling of the production rate from 1972 to 1974 decreases prices 14%; and a further tripling from 1974 to 1975 increases prices 13% so that the net result of a nine-fold increase in production rate is stable prices on a constant dollar basis.

While the number of firms willing to compete in automotive commodities has decreased from the early 1960's, those that do compete almost always do so from existing capacity. Thus, solicitations of interest in competition in the early 1970's often proved fruitless, because there was little excess capacity. When firms were willing to compete, facilitization costs were low, sometimes below $10 million. Brand new entries into the market face capital barriers above $250 million, but almost any existing automotive firm has the infrastructure necessary to compete in this commodity class.

Post award claims were a significant risk posed by automotive competitions. This may be due to the greater reliance in fixed price contracts, than other systems acquisitions combined with the use of Technical Data Package competitions. Four programs experienced claims.

APPLICATIONS TO PROSPECTIVE COMPETITIONS

It should be obvious to even the casual observer that significant variation in competitive and sole source cases exists from commodity to commodity, as well as within commodities. Any analyst or program manager facing a decision to compete a system must examine the particular system

carefully in the context of both its commodity class and the competitive database. It is, therefore, very important that data be collected by commodity class, if decision makers are to make proper inferences about the role of competition for their systems. While the competitive cases exhibit an ideal set of price improvement curves for unit recurring prices, nonrecurring costs can dissipate or eliminate these savings.

I would advise any program manager who can afford the cost to conduct a fully study of the effects of competition on their particular system. However, I would like to suggest here a simple approximation model based on the hypothesis that potential savings on a per unit basis decrease relative to the point in production where competition is first introduced.

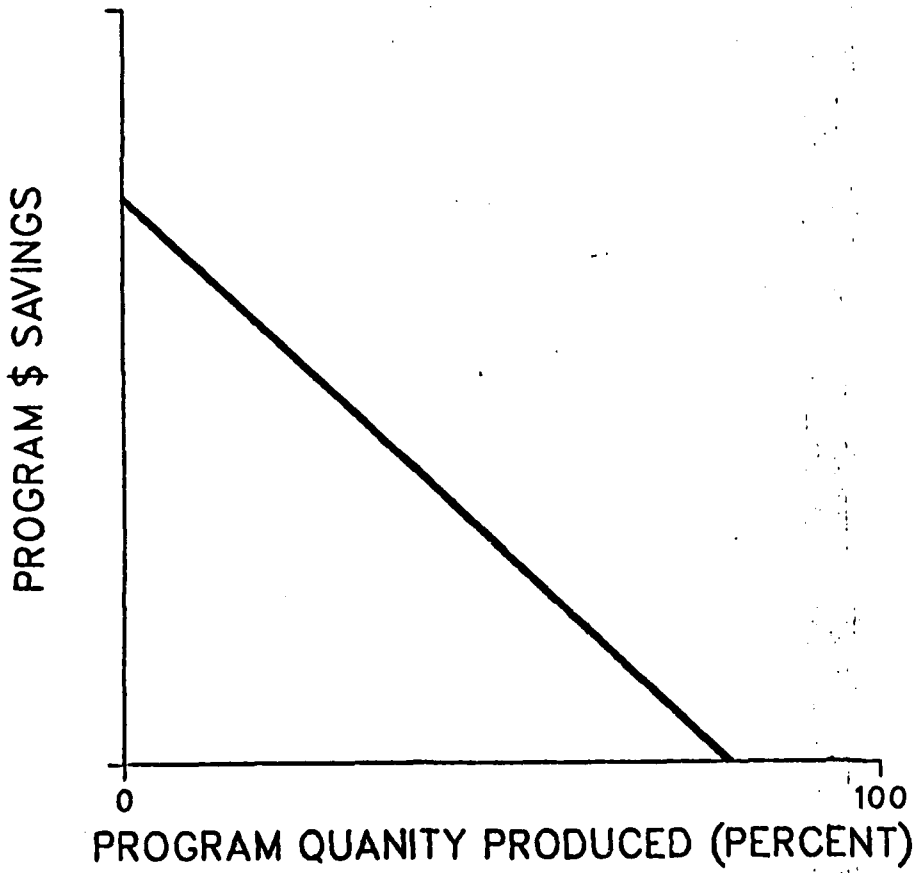
The nature of the predictive model used in competitive studies suggests that the maximum potential savings from the introduction of competition decreases as the point of first competition moves out into the program life cycle. It would appear savings from competition would be of the form:

$$s = k_1 x^a - k_2 x^b$$

where s is competitive savings, x is quantity produced, k_1 and k_2 are first unit constants and a and b are coefficients which determine curve slope. Where competition generates savings b is greater than a. In the best case, with maximum potential savings, this is always the case. Therefore, savings increase in a non-linear relation to increases in quantity competed. The maximum quantity available for competition is the available program quantity. The hypothesis can therefore be restated as: The potential savings from competition in any given system decreases in a non-linear relation to the quantity produced at the point of first competition. Graphs 1 and 2 illustrate the hypothesis. It is important to state the hypothesis in this manner. Simply relating savings to quantity competed

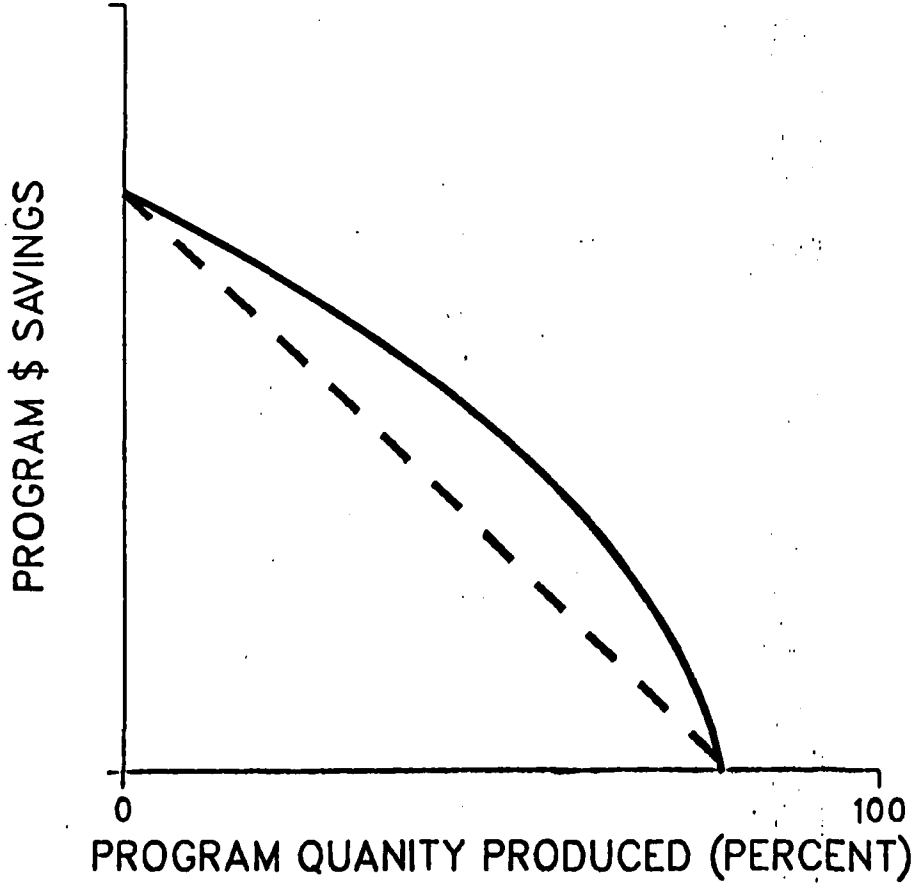
GRAPH 1

POTENTIAL COMPETITIVE SAVINGS
LINEAR



GRAPH 2

POTENTIAL COMPETITIVE SAVINGS
NON–LINEAR



would not account for the potential competitive advantage developed by an incumbent sole source after several years of production.

I offer the hypothesis for further investigation. I have yet to test it mathematically or statistically. The relationship may hold in some situations, but not in others. But, if true, it suggests that every system that is competed, should be competed from the very first production contract and should be competed as many times as possible.

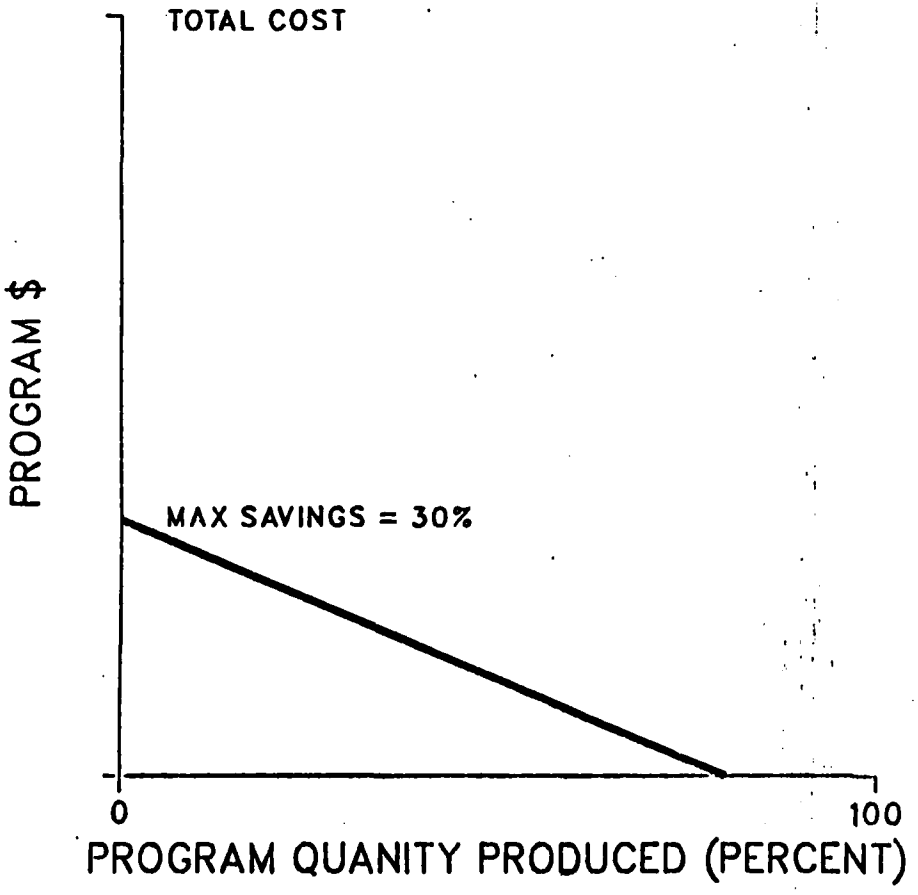
The hypothesis also suggests a simple tool for arriving at a first approximation of the potential for competitive savings for a given system. Program managers who cannot afford a full study of the effects of competition might use this tool to point up the major issues raised by competition. Graph 3 illustrates the technique. Potential savings from competition can be approximated using the maximum observed savings from the available database for a given commodity. That percentage is then applied to the estimated total recurring production cost of the system. This becomes the y-axis intercept. Competition will not generate savings throughout program life. The incumbent will develop an absolute competitive advantage at some point between 50% and 100% program completion. The x-axis represents the degree of program completion from 0% to 100%. The x-axis intercept can be approximated by estimating the size of a minimum economical production run and subtracting from total program quantity and dividing by total program quantity. A straight line is then drawn from the y-intercept to the x-intercept.

Graph 4 illustrates the remaining calculations. First, specifications may not be available for competition for the first production buy, or other restrictions may prevent competing the first production buy. A vertical line is drawn through the graph at the point where competition is first

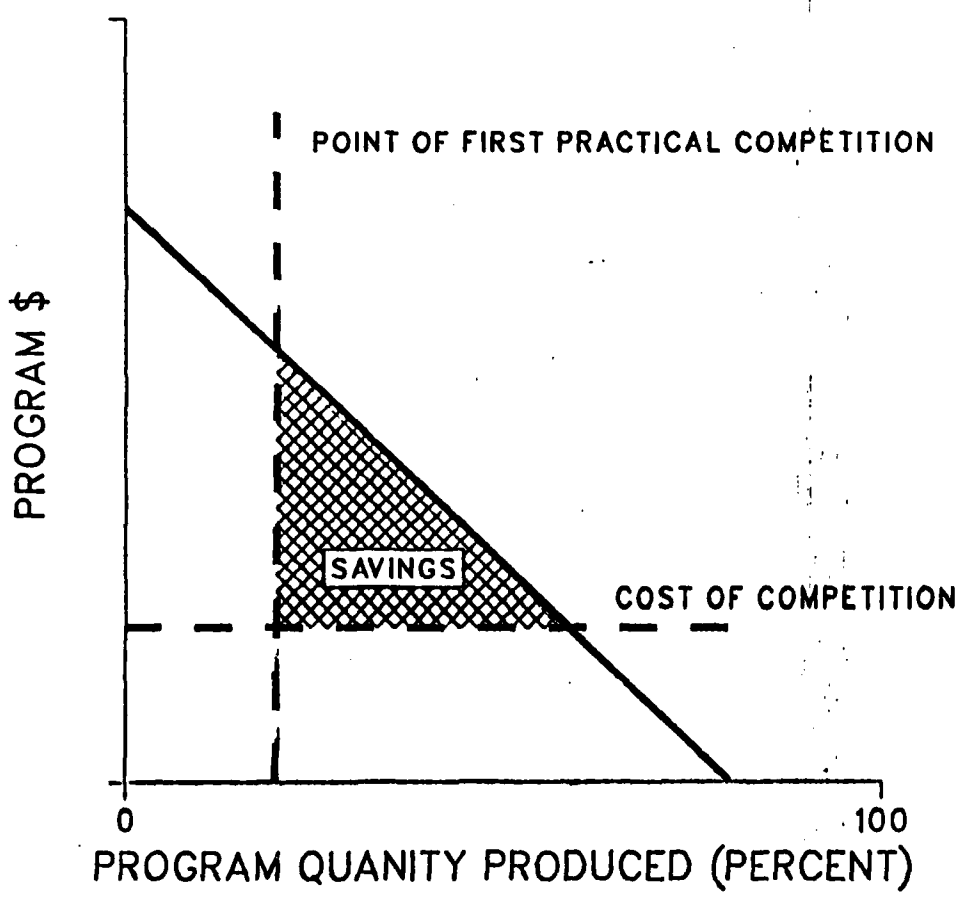
GRAPH 3

SIMPLE APPROXIMATION

STEP ONE



GRAPH 4
SIMPLE APPROXIMATION
STEP 2



feasible. Nonrecurring costs of the competition are then estimated and plotted against a the y-axis, by a horizontal line. If these two lines intersect within the triangle, competition is likely to result in program savings and should be further investigated. If the intersection falls near or outside the triangle, then the probability of generating any savings from competition is low and competition can probably be rejected as an alternative.

APPLICATIONS FOR SHOULD COST STUDIES

Not all production systems can be competed. Some systems are state of the art and are constantly undergoing engineering improvement during production. Some systems require very large capital outlays which raise barriers to competition. Technical specifications such as TDP's adequate for competition may not be available. Schedule requirements may dictate against competition, particularly where Congressionally imposed.

These situations do not absolve either the Government or the prime contractor of their responsibilities for cost control. Considering all the competitive cases available for examination, not one has shown a constant dollar increase. This was the case for vehicles, even where significant engineering changes occurred, such as on the M113 and the M320RT. Obviously, one potential benefit from competition is that it provides a stimulus to find cost reduction improvements, in addition to other engineering changes.

While not all cases or even all commodities show sole source price increases, they are common. One technique for controlling these increases used by the Army is the Should Cost Study. A Should Cost Study convenes a

team of experts to review all aspects of a contractor's proposal and operations in an attempt to find cost reduction measures. For the M113 Family of Vehicles, Should Cost Studies have been reasonably effective. As noted, three studies were conducted on a total of four fiscal year production contracts. A total of 14 line items were studie . Average savings over prior buys were 5.8% in constant dollar terms. Two Should Cost Studies were conducted for the M60A1, and resulted in constant dollar increases. Each was conducted in a unique environment. One encountered very small quantities, and the other was conducted during the M60 Acceleration Program. Numerous other studies have been conducted, but analysis of their effectiveness is beyond the scope of this paper.

Should Cost Studies definitely have the potential to be effective tools for controlling sole source prices. Should Cost teams often concentrate on the fine details of a firm's costs or operations. The available database of weapon system acquisitions indicates the need for an aggregate or pricing approach to be used in conjunction with such detailed investigations. Some applications using the competitive model are discussed below.

Timing of Should Cost Studies

Obviously, Should Costs obtain some of the same types of reductions generated under competition. Should Cost teams often suggest changes in management and production practices, which firms voluntarily seek under competitive pressure. That being the case, the potential savings from Should Costs should parallel competitive savings behavior. The hypothesis suggested here is that Should Costs savings early in production will fall

below competitive savings potential. Unlike competition, Should Costs can be effective at almost any point in production up to program buy-out. Competitive savings potential tends toward zero well before program termination primarily because new sources cannot overcome the competitive advantage of the incumbent. (It is very difficult for a firm producing its first thousand units to compete with a firm which has produced ten thousand units.) Conducting a Should Cost on an item that has substantial production history can still generate savings, just as a system competed continuously from Unit 1 will generate savings over most of its life cycle.

If the hypothesis is correct, then for any system not competed, a Should Cost Study should be conducted for the initial production buy. Where competition has occurred and a sole source follow-on is contemplated, the follow-on buy should be subjected to Should Cost analysis. If the proposed prices do not vary significantly from the competitive baseline, the competitive baseline should be relied upon.

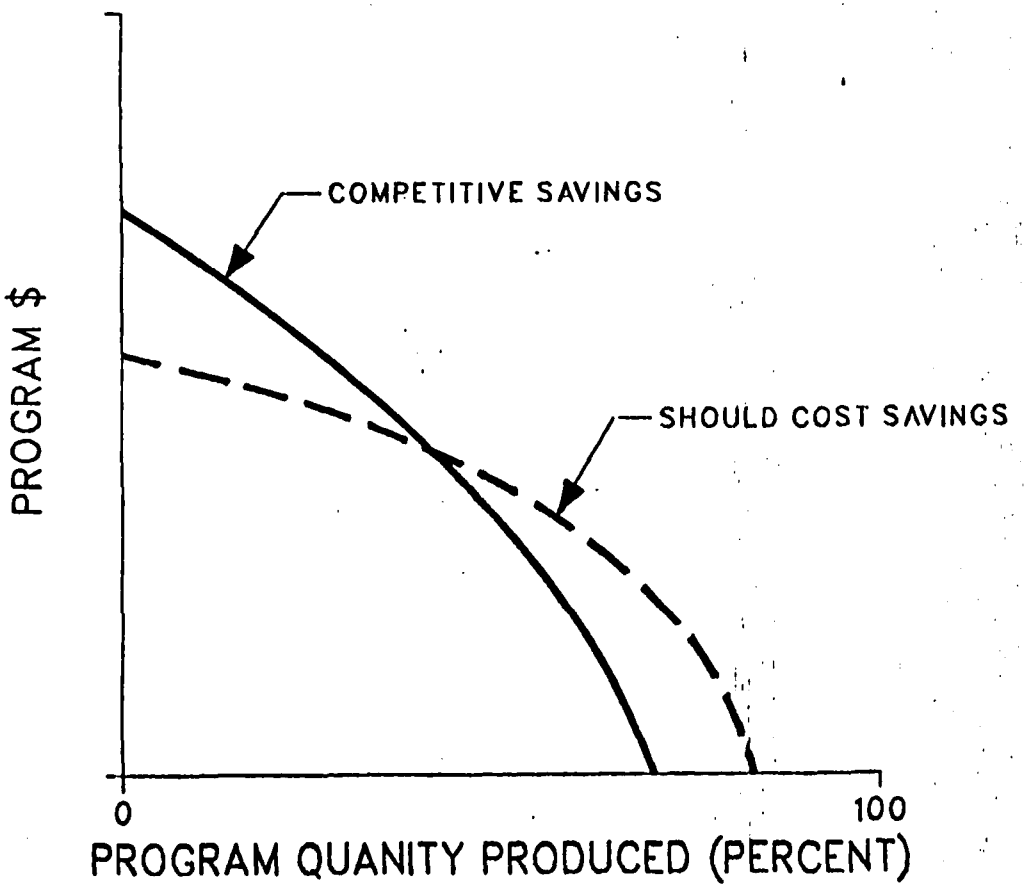
As Graph 5 illustrates, if the point of first competition occurs late in the production life of a program, potentially greater savings can be generated by a Should Cost. A cross-over point exists where the two approaches are equally effective.

Use of the Predictive Model

As noted above, competitive cases indicate every system should lend itself to decreasing constant dollar costs over a continuous production run, so long as the basic configuration is relatively stable. One objective of every Should Cost should be to obtain mutual agreement to a price improvement curve as a goal for successive contracts. Two major

GRAPH 5

COMPETITIVE VS. SHOULD COST POTENTIAL SAVINGS



issues will have to be addressed: curve selection and reaching agreement.

Which Curve?

For studies of initial production contracts, I suggest the Should Cost team formulate a model predicting potential competitive recurring cost savings as if a competition were taking place. The team should concentrate on analyzing the cost behavior of similar systems produced by the same firm, and the behavior of individual cost elements on an overall or aggregate basis, such as total purchased parts or manufacturing labor. The prime contractor should also have a cost reduction team working toward the same objectives, and should have a compensation structure which incentivizes cost reduction behavior of employees and managers. The prime contractor should be encouraged to proposed price improvement curve goals, which represent the firm's judgements of attainable objectives. These aggregate level price improvement curves should then be compared with the set of known cases in the same and similar commodity classes, both for sole source and competitive cases. Objectives should be formulated by use of the model.

Where some actual cost experience exists, and where competitive cases in the same commodity class exist, the competitive cases should be used to develop an estimate of potential savings using actual costs as a baseline. This estimate should then be adjusted to realistically reflect negotiation potential and the reliability of the cost data. Normally, a team will not be able to negotiate as large a reduction as could be achieved through competition.

Obtaining Agreement

Most Contractors will be reluctant to agree to any price improvement curve as a program or contractual goal. The Government must be willing to do its part to stabilize the system design configuration and the contract environment. While the Government may grant configuration control to a firm when the design is fully proven, configuration control should revert back to the Government. We cannot expect even the most efficient, cooperative contractor to systematically reduce costs when a system is being engineered on-the-fly. Stable design is a necessary condition for efficient production. Quantity rate stability enhances the firm's planning capabilities and the opportunities for cost reductions. Otherwise, resourses that might be spent investigating cost reductions will be spent on re-scheduling, re-ordering, and re-arranging the plant to fit the latest Government quantity change. Multi-year contracting may help in this regard.

Profit is presumed to be the primary motivating force for defense contractors. To harness the profit motive, the Government must overcome the perception by many contractors that giving up a dollar of cost is also giving up ten cents (or more) of profit. DAR 3-803 Weighted Guidelines Method of Profit Analysis gives a ready made tool for rewarding productivity gains. Productivity may be considered under "Special Factors." A "Productivity Reward" is calculated based on appropriate cost reduction. The prospective base profit percentage is then applied to this amount to arrive at the additional profit allowed.

Agreement on a price improvement curve for a program can serve as the baseline for the "Productivity Reward" calculation. To be effective, this factor should both increase profits when costs are below the curve targets, and decrease profits when costs are above curve targets; in a similar fashion to incentive-type contracts. The parties must also agree to an appropriate method of inflation adjustment for the cost baseline.

Profit may not always be the motivating factor for a contractor. Contract negotiators must find the key issue for such firms and create a plan which will achieve similar results.

The agreements reached should be expressed in a Basic Agreement, in a Memorandum of Understanding, or the contract between the parties. Verbal negotiation records are not sufficient documentation and do not represent the high level attention these issues deserve.

Follow-on Production Should Costs

The timing of Should Cost Studies for follow-on acquisitions depends on the contractor's performance and the acquisition environment.

When major product improvements or configuration changes take place, a study of the changed program would be appropriate. Study teams should examine several approaches including contructing new price improvement curves from scratch and making one time shifts to historical curves. Similar changes within a commodity class should be examined.

Normally, successive Should Costs would not be required where the contractor is performing at or below the target curve established by the parties. Additional reviews should be conducted where significant cost increases are anticipated, where several years have elapsed, or

significant production rate changes occur.

SUMMARY

The predictive model developed to project savings from competing major weapon systems can be a powerful tool for assessing both competitive and sole source acquisition prices. Successful use of the model depends on the reliability of the historical database for a particular commodity. For automotive commodities, price improvement curves are relatively shallow even for competitive cases. The steepest competitive curve was of 91% slope. Sole source cases often exhibit constant dollar increases. Competitions that occured one-time generated savings of 18%. Should Cost Studies can be effective tools for controlling sole source prices. The effectiveness of the studies can be enhanced by using the predictive model.

DATA APPENDIX

The following data were first presented in the DARCOM Bradley FVS Second Source Reassessment Team report. It is reproduced in its entirety with the permission of the Team Chairman.

TABLE D-1

INFLATION FACTORS (DEC 80 = 1.00)

CALENDER YEAR	FACTOR
1960	3.23
1961	3.23
1962	3.20
1963	3.18
1964	3.18
1965	3.10
1966	3.01
1967	2.95
1968	2.85
1969	2.74
1970	2.62
1971	2.52
1972	2.43
1973	2.27
1974	1.90
1975	1.70
1976	1.59
1977	1.48
1978	1.38
1979	1.23
1980	1.07
1981	.96
1982	.90
1983	.82
1984	.74
1985	.68

TABLE D-2

M113 FAMILY OF VEHICLES

M113 ARMORED PERSONNEL CARRIER

FY	FOV QTY	AWD PRICE	ACTUAL	FACTOR	DEC 80 $	TYPE
59	375	29396	38911	3.23	125683	FPR
59	525	29457	30663	3.23	99041	FPR
60	874	26639	26525	3.23	85676	C, FPR
61	806	26100	26100	3.20	83520	FPR
61	1500	24480	24274	3.20	77677	C, FPR
62	1500	24326	24274	3.18	77191	FPR
62	1632	20128	20128	3.18	64007	C, FFP
62	1132	20910	20910	3.18	64494	FFP
62	1200	20128	20128	3.18	64007	C, FFP
62	694	19500	19500	3.15	61425	FFP
63	2030	19116	19116	3.15	60215	C, FFP
63	2365	19084	19084	3.15	60115	FFP
63	1188	18800	18800	3.15	59220	FFP
A1 64	4262	19469	19469	3.10	60354	FFP
65	2755	17369	19114	3.01	57533	C,M, FPE
66	2419	18098	19844	2.95	58540	C,M, FPE
67	3675	19402	20365	2.85	58040	C,M, FPE
67	3285	22692		2.74	62176	M, FPI
68	500	23210		2.74	63595	M, FPI
69	745	22700	22700	2.57	58339	FFP
69,70	4438	19832	21012	2.57	54001	C,M, FFE
71	1620	19832	25099	2.43	60991	C,M, FPE
72	994	24995		2.43	60738	FPE
73	1501	32000		2.27	72640	FPE
74	4366	41393		1.70	70368	FPI
75	729	39148		1.59	62245	S FPI
76	1729	41212		1.48	60994	S FPI
77	3812	42556		1.38	58727	S FPI
78	2308	51379		1.23	63196	FPI
A2 79	1187	68536		1.07	73334	FPI
80	2059	76290		.96	73238	S FPI
81	946	91939		.90	82745	FPI

LEGENDS:
C - Competitive
M - Multi-Year
S - Should Cost
FPR - Fixed Price Redeterminable
FFP - Firm Fixed Price
FPE - Fixed Price With Economic Price Adjustment
FPI - Fixed Price Incentive

TABLE D-2

M113 FAMILY OF VEHICLES (CONTINUED)

M125 - SELF PROPELLED MORTAR

FY	QTY	AWD PRICE	FACTOR	DEC 80 $	TYPE
65	363	19797	3.01	59589	C,M, FPE
67	509	24200	2.85	68970	FFP
67	95	27679	2.74	75840	M, FPI
69	202	24859	2.57	63888	C,M, FPE
72	45	33300	2.43	80919	FPE
73	NO ACQUISITION				
74	687	51782	1.70	88029	FPI
75	33	50109	1.59	79673	S FPI
76	30	55756	1.48	82519	S FPI
77	69	54406	1.38	75080	S FPI

M106 - SELF PROPELLED MORTAR

FY	QTY	AWD PRICE	FACTOR	DEC 80 $	TYPE
63	840	24287	3.15	36504	C, FFP
64	640	22326	3.10	69211	FFP
65	28	18932	3.01	56985	C,M, FPE
67	152	23450	2.85	66833	FFP
69	302	23459	2.57	60290	C,M, FPE
72	1	37500	2.43	91125	FPE
73	24	42741	2.27	97022	FPE
74	NO ACQUISITION				
75	NO ACQUISITION				
76	17	53364	1.48	78979	S FPI
77	50	53770	1.38	74203	S FPI

M577 - COMMAND POST

FY	QTY	AWD PRICE	FACTOR	DEC 80$	TYPE
62	270	25935	3.18	82473	C, FFP
63	674	21525	3.15	67804	FFP
64	1225	23418	3.10	72596	FFP
65	557	02858	3.01	62783	C,M, FPE
67	216	25850	2.85	73673	FFP
67	205	28380	2.80	79464	M, FPI
69	662	24774	2.57	63669	M, FPE
72	241	31750	2.43	77153	FPE
73	308	42453	2.27	96368	FPE
74	59	50700	1.70	86190	FPI
75	36	50505	1.59	80398	S FPI
76	131	54067	1.48	80019	S FPI
77	105	53711	1.38	74121	S FPI

TABLE D-2

M113 FAMILY OF VEHICLES (CONTINUED)

M548 - CARGO CARRIER

FY	QTY	AWD PRICE	FACTOR	DEC 80 $	TYPE
65	2455	16187	3.01	48723	C,M, FPE
67	507	20000	2.85	57000	FFP
67	412	25950	2.74	71103	M, FPI
67	120	27679	2.74	75191	FPE
69	NO ACQUISITION				
70	NO ACQUISITION				
71	NO ACQUISITION				
72	NO ACQUISITION				
73	285	33736	2.27	76578	FPE
73½	188	37684	2.00	75368	FPI
74	116	46202	1.70	78543	FPI
75	NO ACQUISITION				
76	64	48440	1.48	71691	S FPI
77	275	51441	1.38	70989	S FPI

SOURCES: Procurement Hisotry, FY76 Should Cost Files
Undated Pricing Study, M113 Prices, Circa 1963
TACOM Pricing Files
M113 Should Cost Files
M113 Should Cost Studies

TABLE D-3

M60 TANK ACQUISITION HISTORY

FY	QTY	AWD PRICE	FACTOR	DEC 80 $	TYPE
59	360	119811	3.23	386990	FFP
60	885	83212	3.23	268775	C, FFP
61-63	2210		MISSING DATA		
64	360	86985	3.10	269654	FFP
65	246	93959	3.01	282817	FFP
66	314	94077	3.01	283172	FFP
67	NO ACQUISITION				
68	300	109244	2.85	311345	FFP
69	117	125936	2.74	345065	FFP
70	300	143687	2.62	376460	FFP
71	450	145313	2.52	366189	FFP
72,73	338	159755	2.43	388205	S FFP
74	480	174490	1.90	331531	FFP
75	1240	221272	1.70	376162	S FFP
76	1201	252200	1.59	400998	FFP

SOURCES: FY60 Award Recommendation
1974 Congressional Inquiry Files
TACOM Pricing Files
TACOM Historical Procurement Files

TABLE D-4

M88 HEAVY RECOVERY VEHICLE ACQUISITION HISTORY

FY	QTY	AWD PRICE	FACTOR	DEC 80 $	TYPE
60	200	87068	3.23	281230	C FFP
61	354	87362	3.20	279558	FFP
62	498	82358	3.18	261898	C FFP
AI 76	233	261200	1.48	386576	FFP
77	248	286700	1.38	395646	FFP
78 NO ACQUISITION					
79	78	350000	1.00	350000	FFP
79	106	363000	.96	348480	FFP
80	210	403973	.90	363576	FFP
80	95	441785	.82	362264	FFP

SOURCES: FY60 Award Recommendation
TACOM Pricing Files

TABLE D-5

ARRCOM TRACKED VEHICLE ACQUISITION HISTORIES

PROGRAM	FISCAL YEAR	QTY	UNIT PRICE	FACTOR	DEC 80 PRICE	TYPE
M109AIB	72	20	105,300	2.27	239,031	FFP
	73	91	123,672	1.90	234,977	FFP
	74	366	133,556	1.70	227,045	FFP
	75 NO ACQUISITION					
	76	134	183,099	1.48	270,986	FFP
	77	94	214,658	1.38	296,228	FFP
	78	17	248,095	1.23	305,157	FFP
	79	218	301,360	1.07	322,455	FFP
	80	207	268,970	.96	258,211	FFP
M109A2	76	12	175,199	1.48	259,295	FFP
	77	353	208,911	1.38	277,257	FFP
	78	267	238,945	1.23	293,902	FFP
	79	242	338,106	1.07	361,773	FFP
	80	187	258,166	.96	247,839	FFP
M110A1/A2	74	88	116,261	1.70	197,644	FFP
	75 NO ACQUISITION					
	76	42	152,572	1.48	225,807	FFP
	77	245	192,261	1.38	265,320	FFP
	78	41	222,778	1.23	274,017	FFP
	79 NO ACQUISITION					
	80	132	246,026	.96	236,185	FFP
M578	74	282	124,510	1.70	211,667	FFP
	75	159	140,551	1.59	223,476	FFP
	76	251	161,092	1.48	238,416	FFP
	77 NO ACQUISITION					
	78	12	278,300	1.23	342,309	FFP
	79	3	254,850	1.07	272,690	FFP
	80	43	270,136	.96	259,331	FFP

SOURCE: FONECON, MR. DIVANY, ARRCOM, 17 MAR 82

References

1. Daly, George G., Howard P. Gates and James A. Schuttinga, The Effect of Price Competition on Weapon System Acquisition Cost, Arlington VA: Institute for Defense Analysis, September, 1979.

2. Cox, Larry W. and Jacques S. Gonsler, Evaluating the Impact of Quantity, Rate, and Competition for Production of Weapon Systems, The Analytical Sciences Corporation, May, 1981.

Sources

Cox, Larry and M. Bohn, A Model for Acquisition Strategy Comparisons, The Analytical Sciences Corporation, October, 1981.

Drinnon, S. W., and J. R. Hiller, Predicting the Costs and Benefits of Competitive Production Sources, The Analytical Sciences Corporation, December, 1979.

Lovett, Edward T. and Monte G. Norton; Determining and Forecasting Savings from Competing Previously Sole Source/Noncompetitive Contracts, Army Procurement Research Office, APRO 709-3, Fort Lee, VA: APRO, October, 1978.

Smith, Charles H., Robert F. Williams, and Charles M. Lowe, Jr., Strategy Selection for the Production Phase of Weapon System Acquisition, Fort Lee, VA: Army Procurement Research Office, January, 1982.

Trainor, Richard J., Price Competition Between Major Weapon System Contracts, Trainor Associates, Undated.

Contract and Data Files

M113: FY 75 M113 Should Cost Study, TACOM

FY 77 M113 Should Cost Study, TACOM

FY 80 M113 Should Cost Study, TACOM

Undated "Price Study, 1959 - 1962"

_____ M113 Should Cost Files

TACOM Pricing Files

"Procurement History, M113 Family of Vehicles - as of 1 Mar 72"

TACOM Archives

WECOM Microfiche Archives

M60: Award Recommendation, FY 60 M60 and M38 Programs

M60 Historical Files (Procurement)

1974 Congressional Inquiry Files

TACOM Pricing Files

TACOM Archives

FY 72 M60 Should Cost Study, WECOM

FY 75 M60 Should Cost Study, TACOM

WECOM Microfiche Archives

M88: Award Recommendation, Fy 60 M60 and M88 Programs

Negotiation Memoranda, FY 61 and FY 62

TACOM Pricing Files.

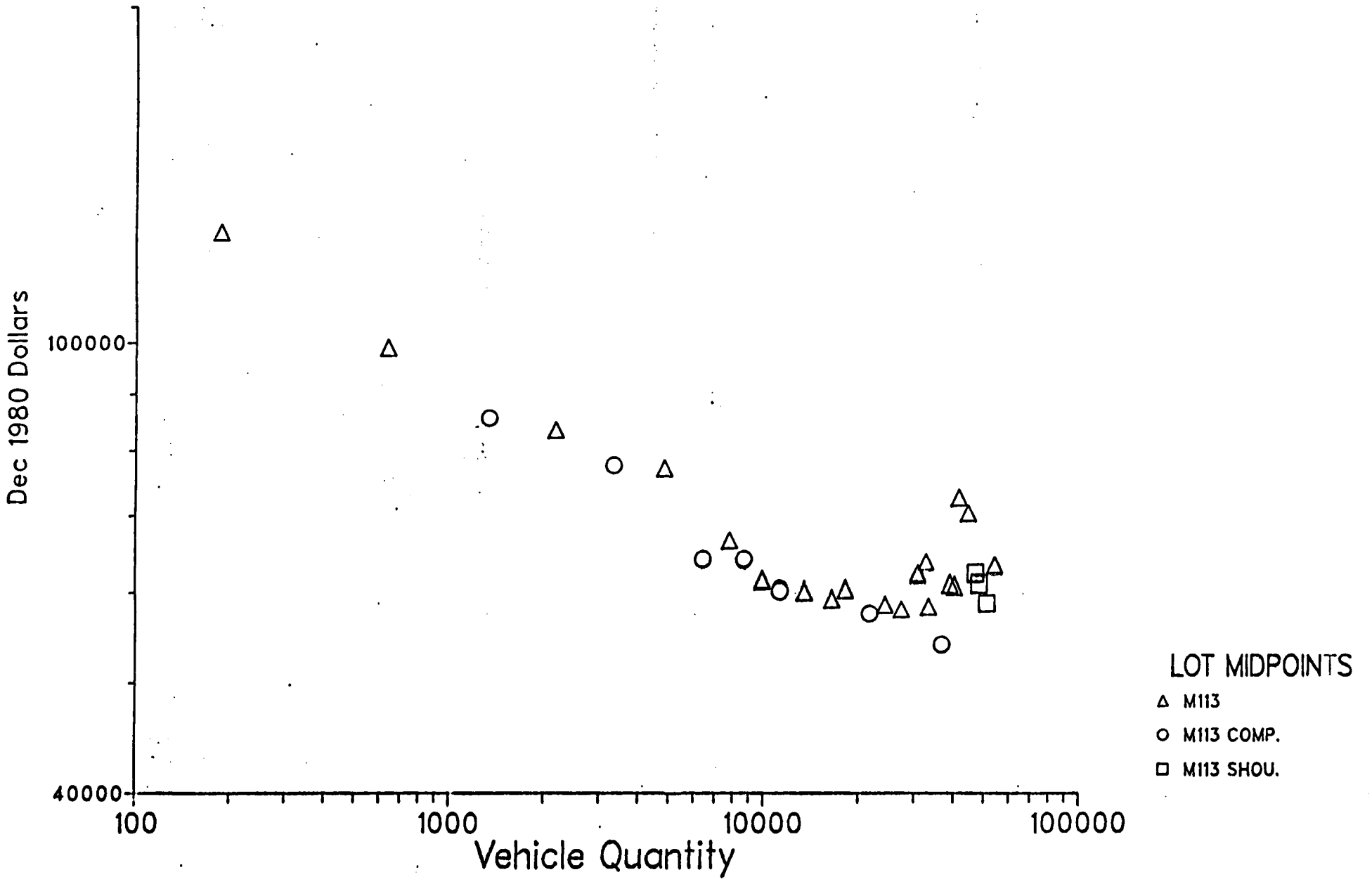
M109/M110 Family of Vehicles: TELECON, Mr. Divany, ARRCOM

M320RT: Contract Files, TACOM

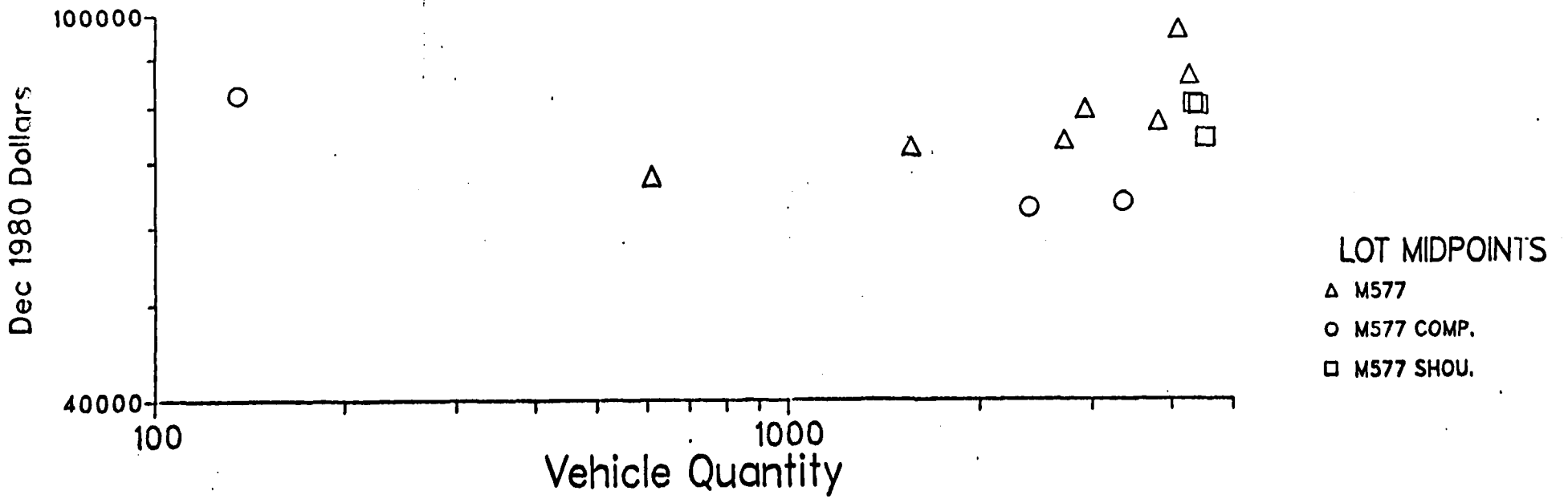
Wheeled APC's: TACOM Pricing and Contract Files

T-3: TACOM Contract Files.

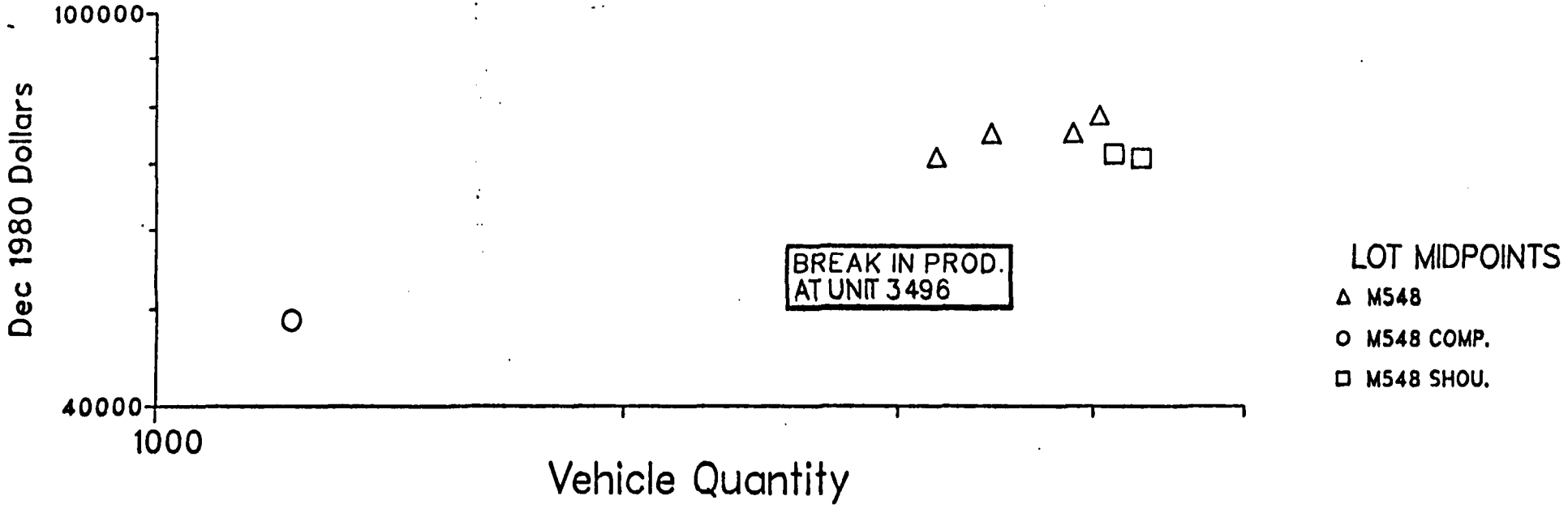
M113 Data


Dec 1980 Dollars
100000
40000
100
1000
10000
100000
Vehicle Quantity
LOT MIDPOINTS
M113
M113 COMP.
M113 SHOU.

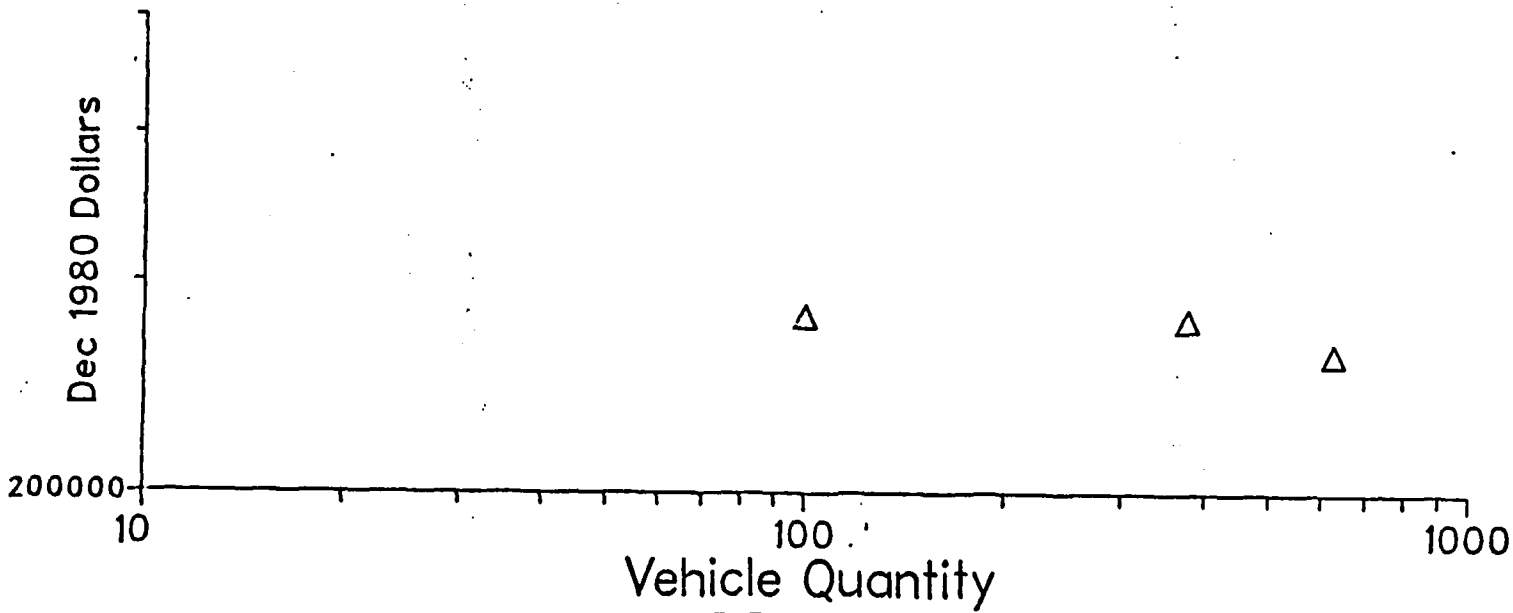
M577 Data


100000
40000
Dec 1980 Dollars
100
1000
Vehicle Quantity
LOT MIDPOINTS
M577
M577 COMP.
M577 SHOU.

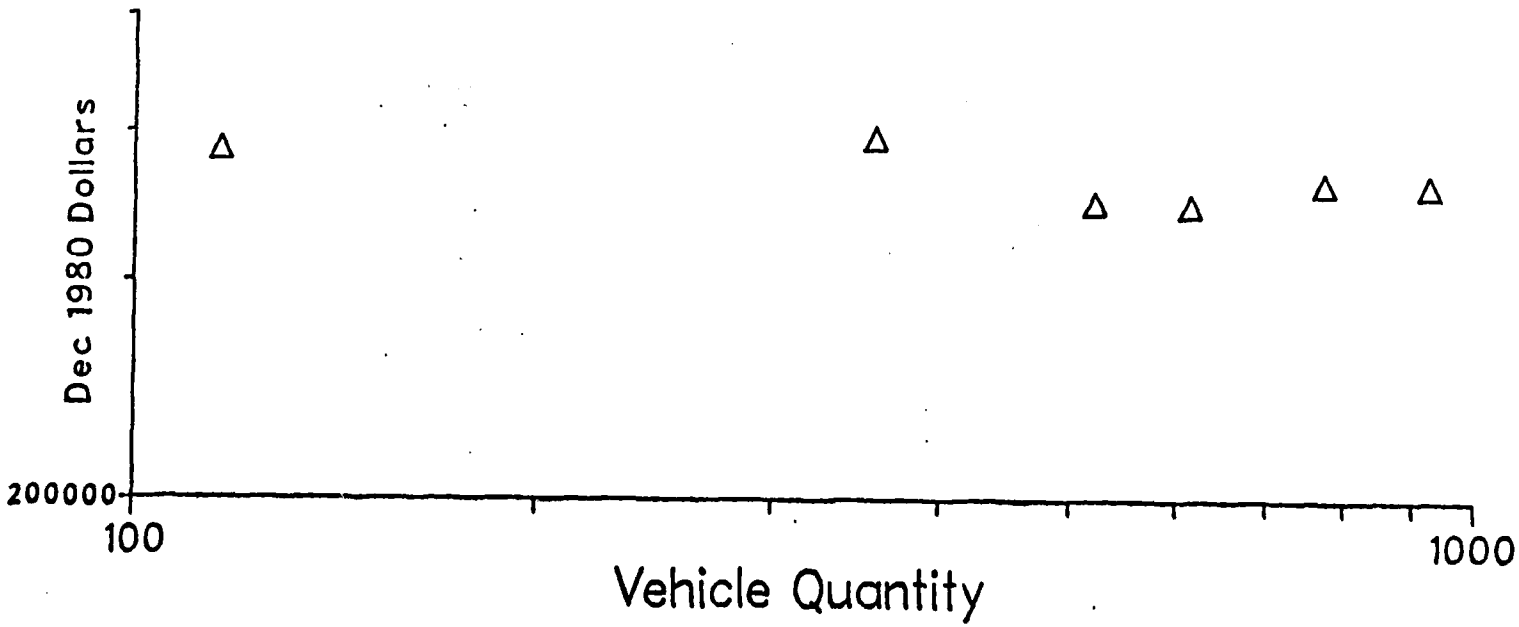
M548 Data


100000
40000
1000
Dec 1980 Dollars
Vehicle Quantity
BREAK IN PROD.
AT UNIT 3496
LOT MIDPOINTS
M548
M548 COMP.
M548 SHOU.

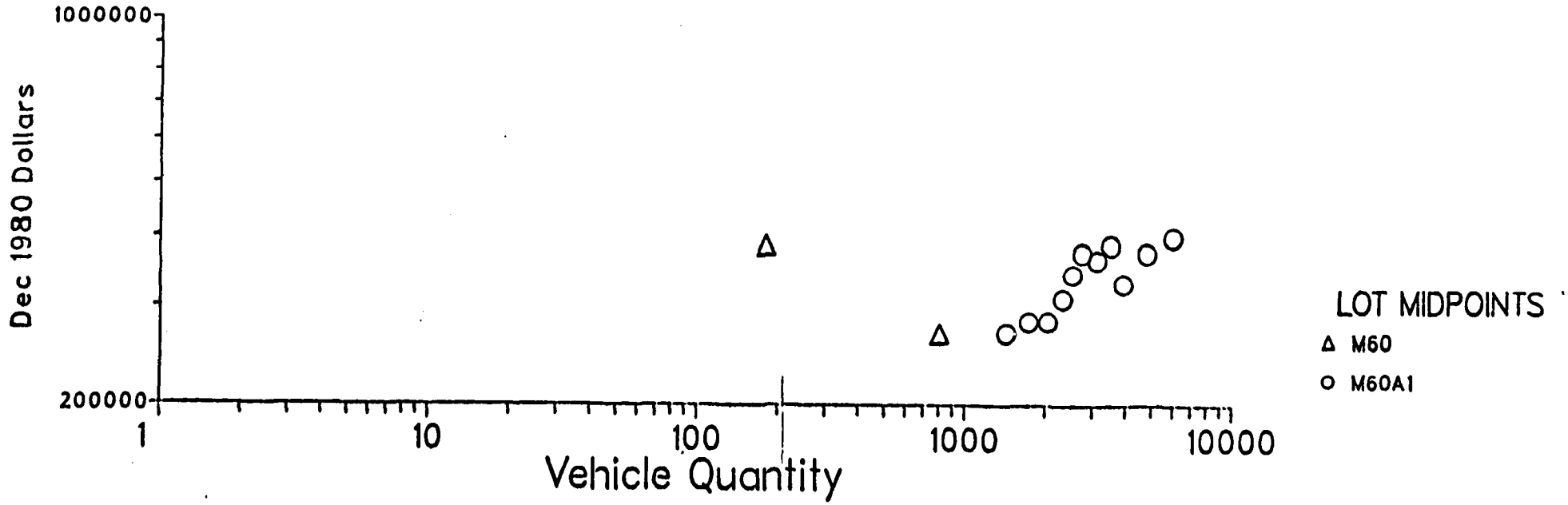
M88 Data



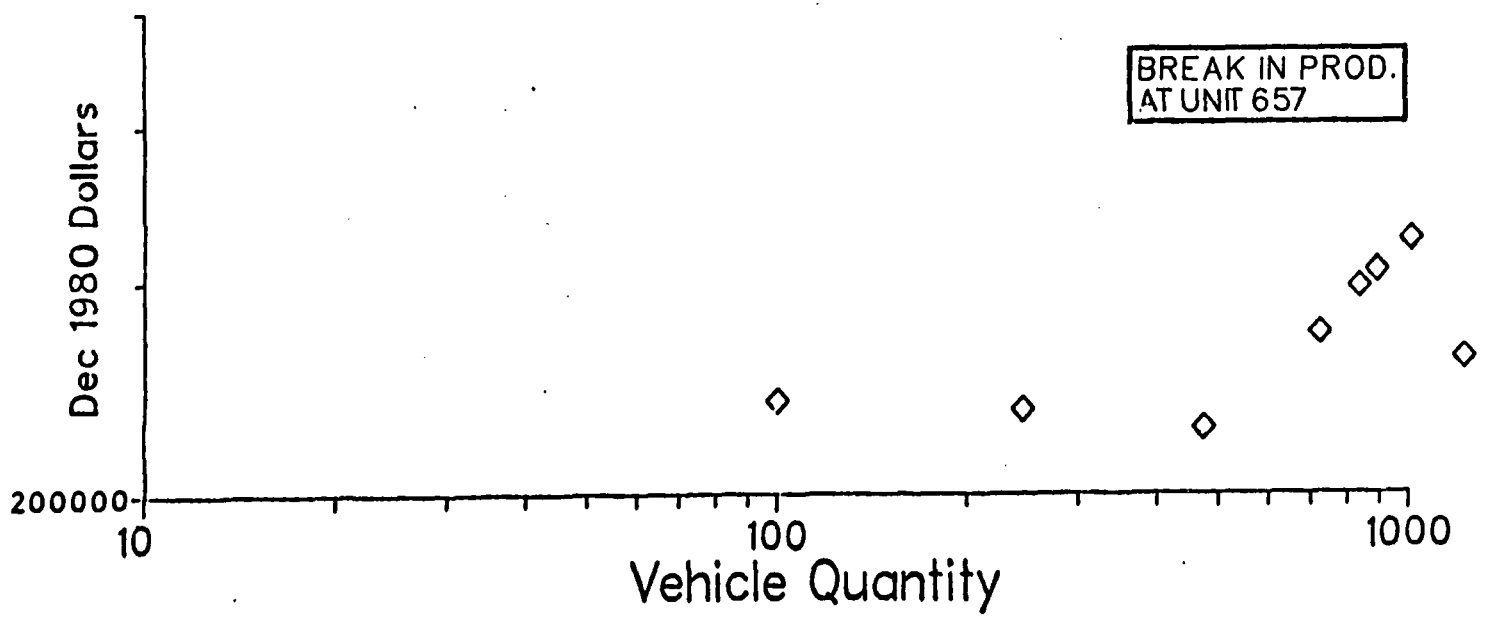
M88A1



M60 & M60A1 Data



M109A1B Data



AD P000227

(12)

Test Shoots
N5100.9(100

COST

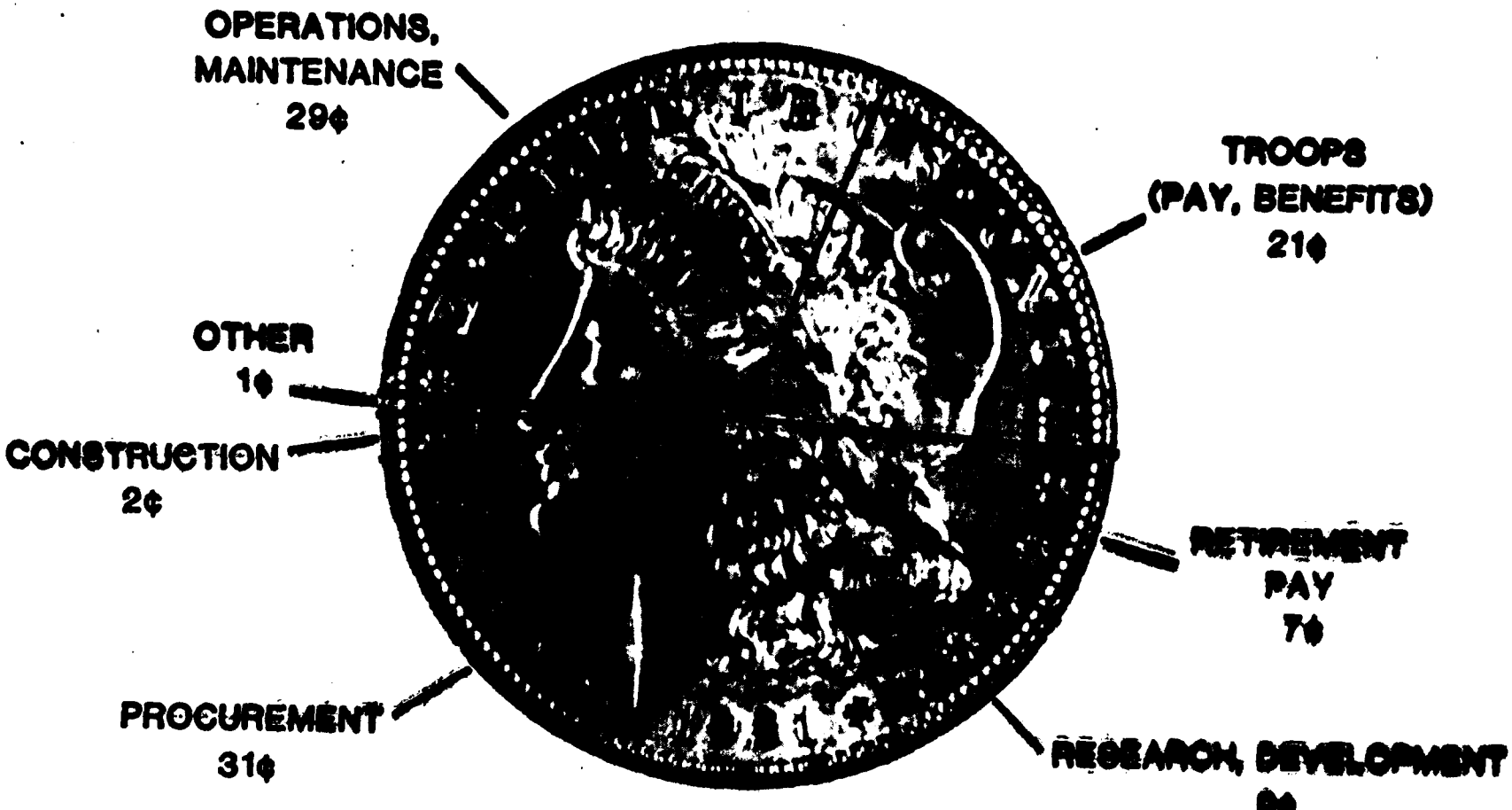
CONTROL

DEFINITION

"CONTRACT COST CONTROL"
IS THE FUSING OF FISCAL'
ENGINEERING AND PRODUCTION
ANALYSES INTO AN ORGANIZED
PROCEDURE IN ORDER TO ACQUIRE
A SYSTEM, COMPONENT OR
SERVICE FOR THE LEAST COST

DIVIDING THE MILITARY DOLLAR

OUT OF EACH $1 SPENT BY THE ARMED SERVICES FOR 1982, HERE'S HOW MUCH WILL GO FOR MAJOR PURPOSES –



PROGRAM EVOLUTION

- SPECIFICATIONS
- OUTLINE DRAWING
- IDENTIFY COST DRIVERS AND REDUCE COST
- INITIAL SET OF DRAWINGS
- PRE-PRODUCTION BUILD
- FINAL SET OF DRAWINGS
- FIRST PRODUCTION

METHODS TO CONTROL COST

- DESIGN TO COST/DTUPC
- VALUE ENGINEERING
- MFG PRODUCTION ENG
- SHOULD COST
- MULTI-YEAR BUY
- ECONOMICAL PRODUCTION RATES
- CONTRACT COST CONTROL

LIFE CYCLE COST DRIVERS

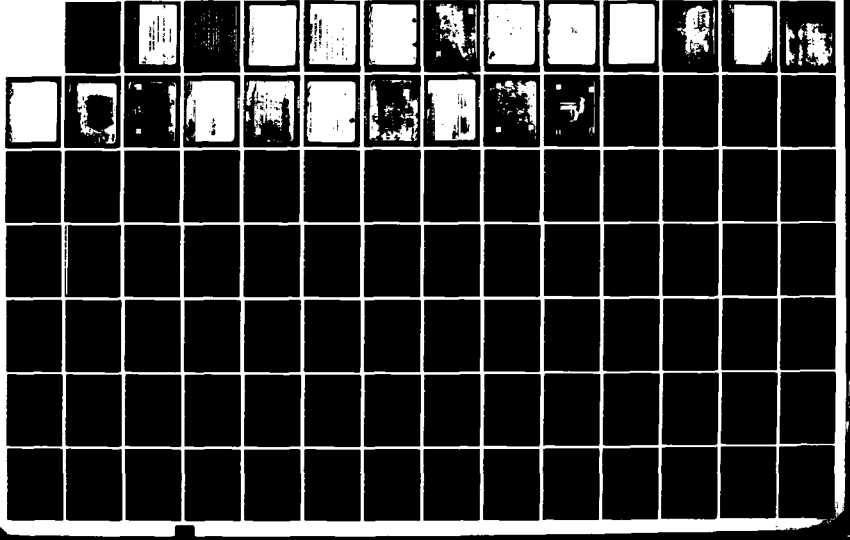
- PRODUCTION UNIT COST
- RELIABILITY/MTBF
- REPAIRABILITY/MAINTAINABILITY/MTTR
- ILS/SPARES

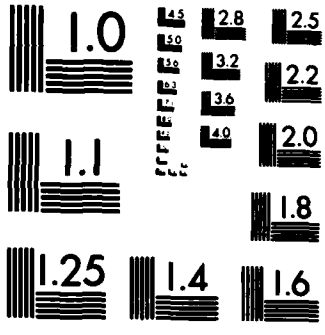
PRODUCTION UNIT COST

- COMPLEXITY OF DESIGN
- STATE-OF-THE-ART
- MATERIALS
- EASE OF ASSEMBLY/TESTING
- EASE OF MANUFACTURE
- EMBEDDED SOFTWARE

AD-A130 418 DEPARTMENT OF DEFENSE ANNUAL COST ANALYSIS SYMPOSIUM (17TH) HELD AT ARLINGTON VIRGINIA ON 12-15 SEPTEMBER 1982(U) OFFICE OF THE CHIEF OF NAVAL OPERATIONS WASHINGTON DC SEP 82 2/6

UNCLASSIFIED F/G 15/5 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

COST CONTROL FUNCTION

PROVIDE CONTRACT LIAISON SERVICES FOR:

1. PROGRAM MANAGEMENT
2. CONTRACTING OFFICER
3. ENGINEERING

FUNCTIONAL SERVICES FOR PROGRAM MANAGEMENT

1. EVALUATE ENGINEERING SUPPORT HOURS AS RELATED TO BASIC DESIGN AND/OR HARDWARE (A 109 CONCEPT)
2. EVALUATE PRIME CONTRACTOR ESTIMATES ON WEAPON SYSTEMS
3. EVALUATE IMPROVEMENT CURVES
4. EVALUATE COST INCREASES DUE TO CHANGES IN NUMBER OF WEAPONS PROCURED
5. PLOTTING OF COST CURVES ON UNIT COST
6. ATTEND MEETINGS DEALING WITH DESIGN OR MANUFACTURING PROBLEMS
7. ESTIMATE DIRECT PERSONNEL REQUIREMENT
8. PREPARE REPORTS ON COST, SCHEDULING AND PROGRESS OF THE CONTRACTOR

FUNCTIONAL SERVICES FOR CONTRACTS

FUNCTIONAL SERVICES/PRODUCTION FOR ENGINEERING

1. EVALUATE DESIGN FOR PRODUCIBILITY
2. CHECK MANUFACTURING PROCESS SHEETS
3. ATTEND PRODUCTION SCHEDULE MEETINGS
4. RECOMMEND ALTERNATE MANUFACTURING METHODS TO REDUCE COST

CONTRACT COST CONTROL

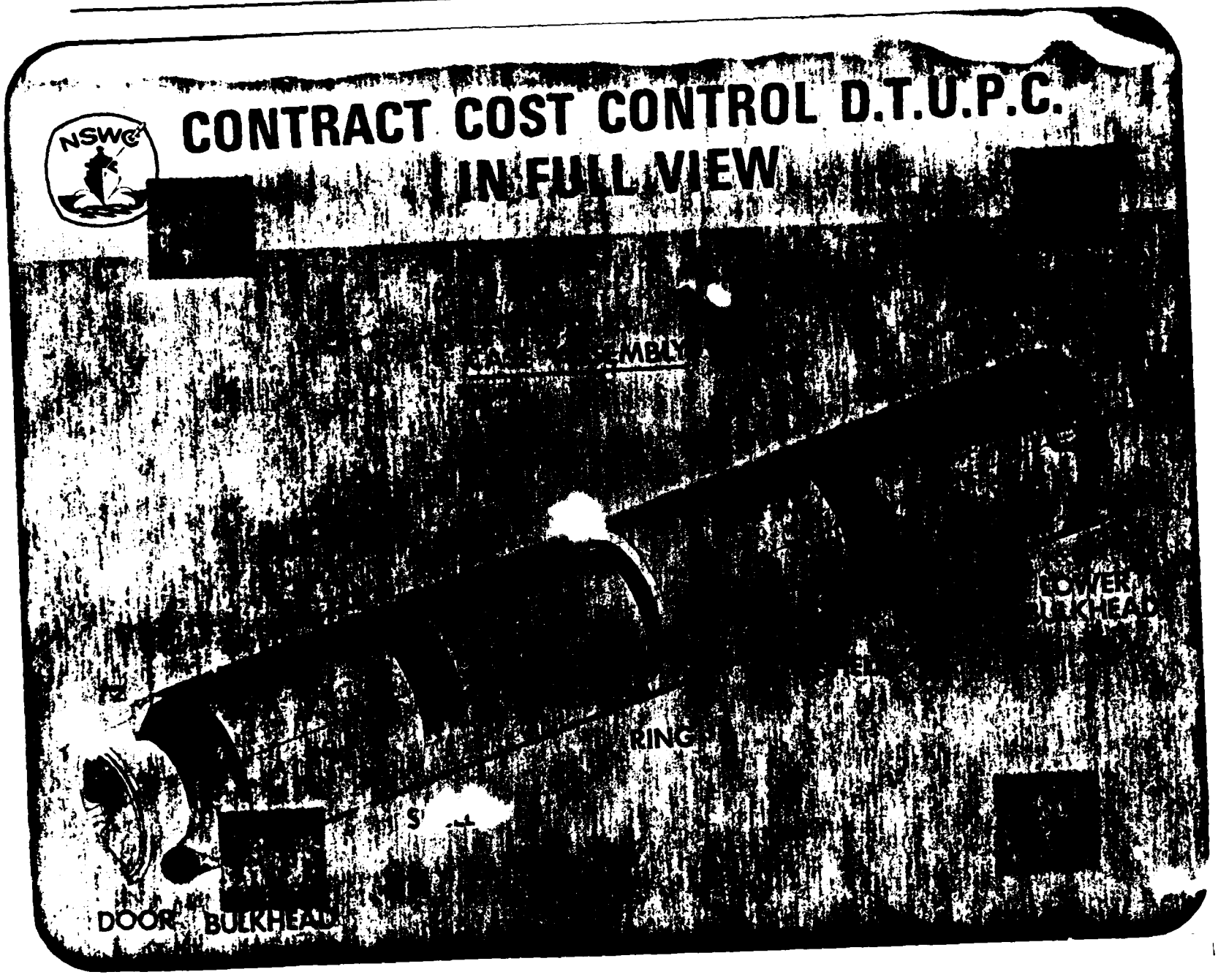
FUNCTION IN R&D

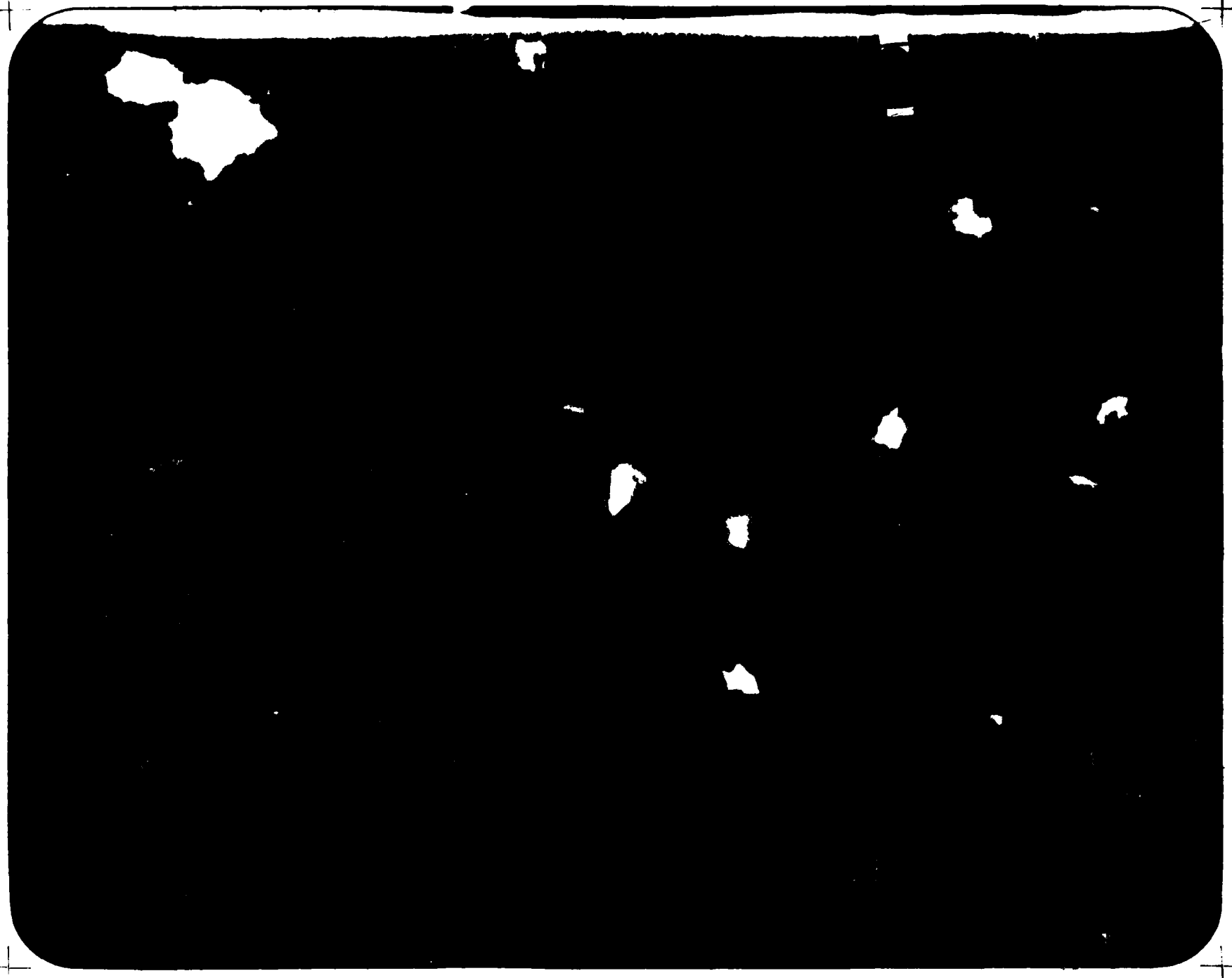
1) EVALUATE ENGINEERING SUPPORT HRS AS RELATED TO BASIC DESIGN (A 109 CONCEPT)

2) DEVELOP A DESIGN TO UNIT PRODUCTION COST (DTUPC) OBJECTIVE IN FORM OF A COST MODEL

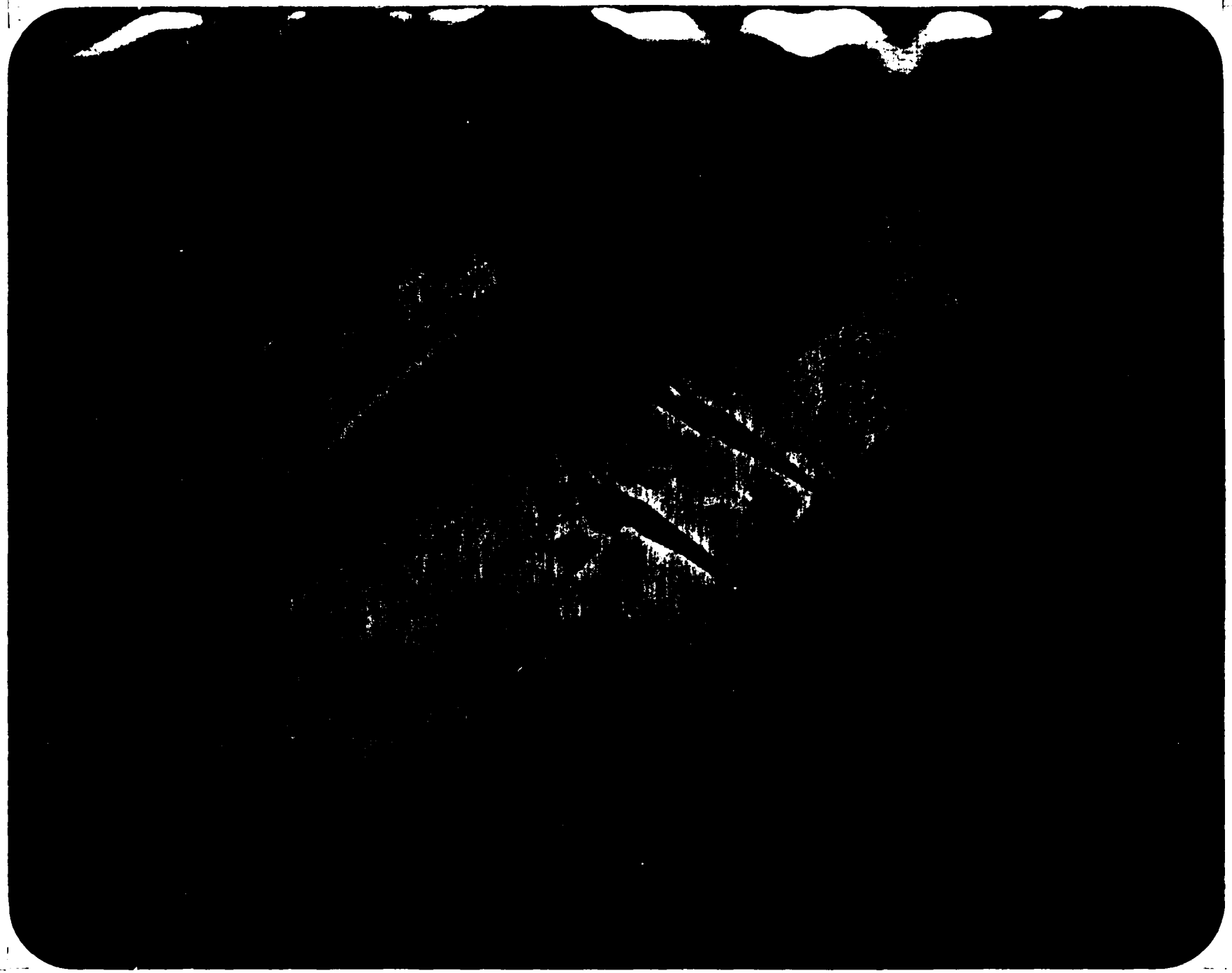
3) EVALUATE MFG PROCESS SHEETS PROCEDURES AS IT EQUATES TO THE DESIGN DISCLOSURES

4) REQUIRE FOR ALL CONTRACTORS

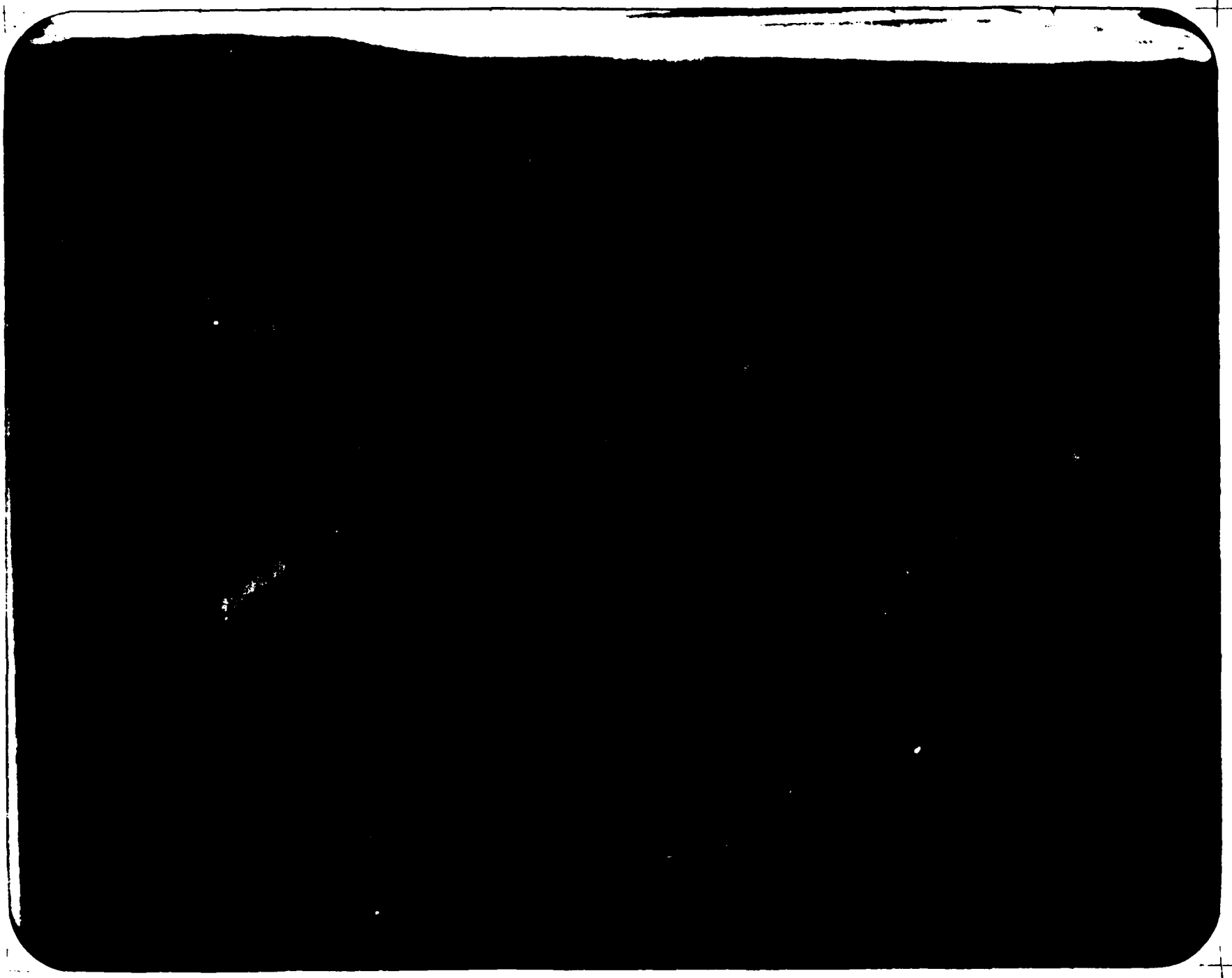

CONTRACT COST CONTROL D.T.U.P.C.
IN FULL VIEW
NSWC
DOOR BULKHEAD



GEMINI

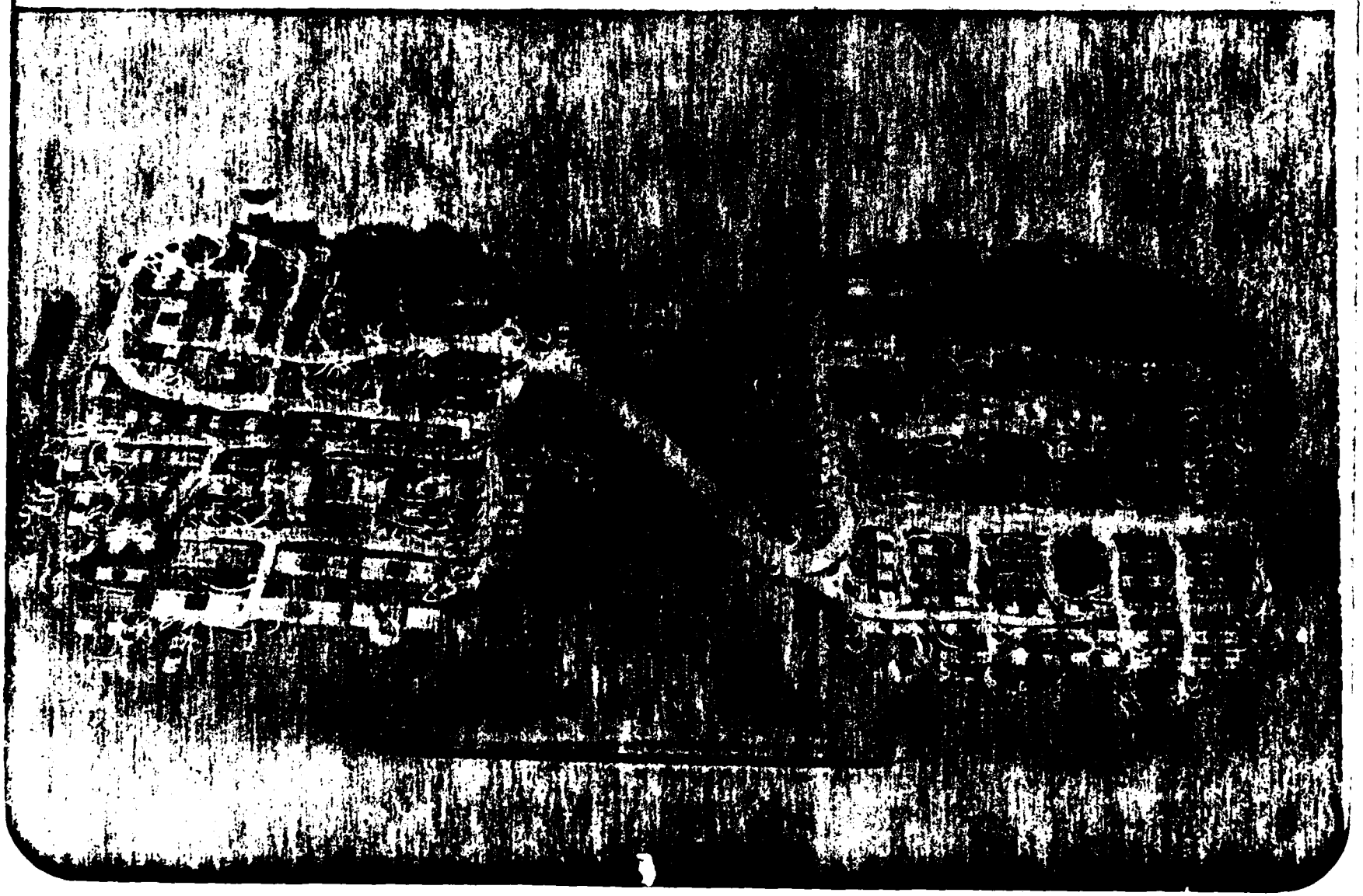


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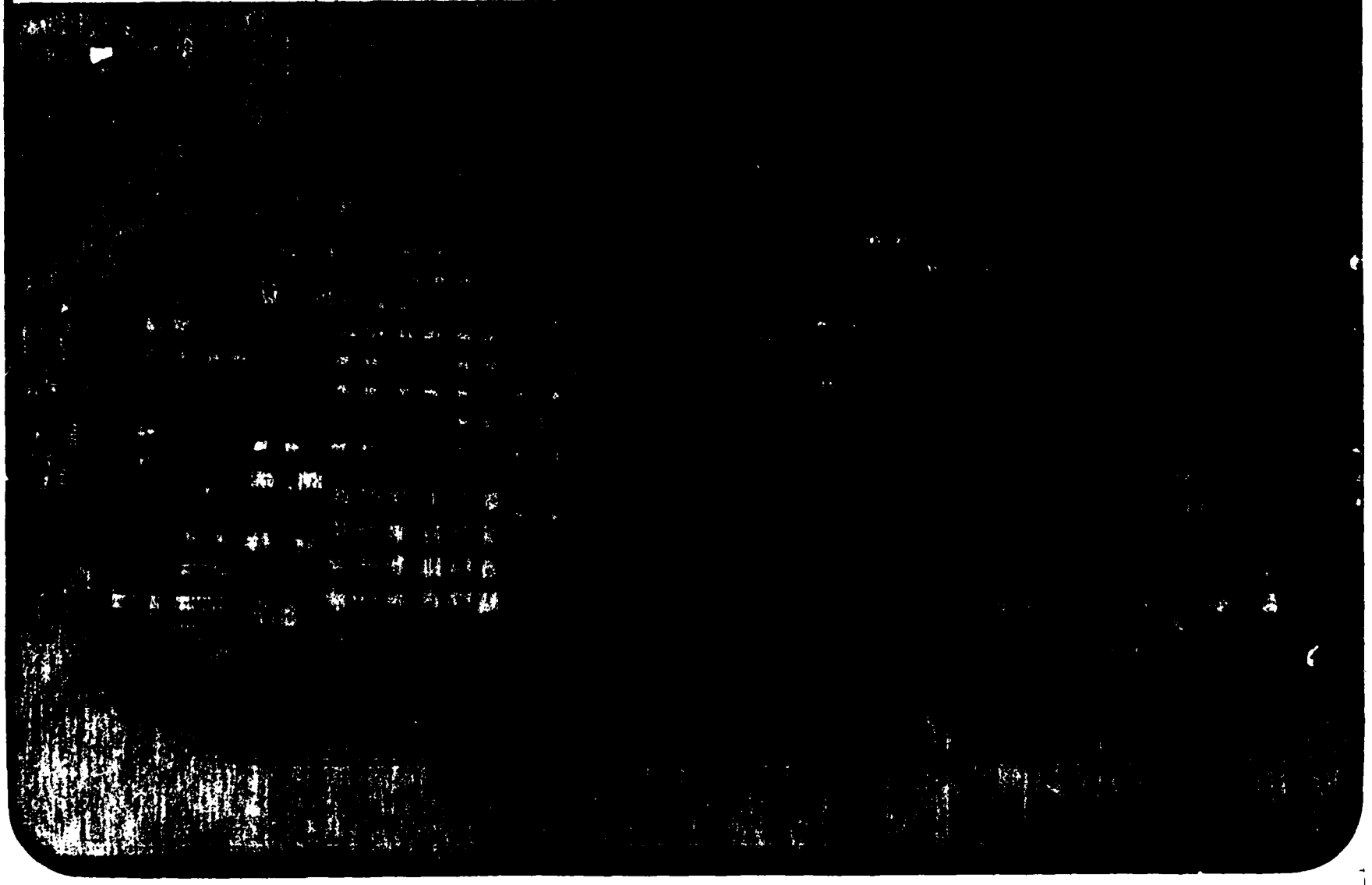


GEMINI

C.C.C DESIGN TO UNIT PRODUCTION COST

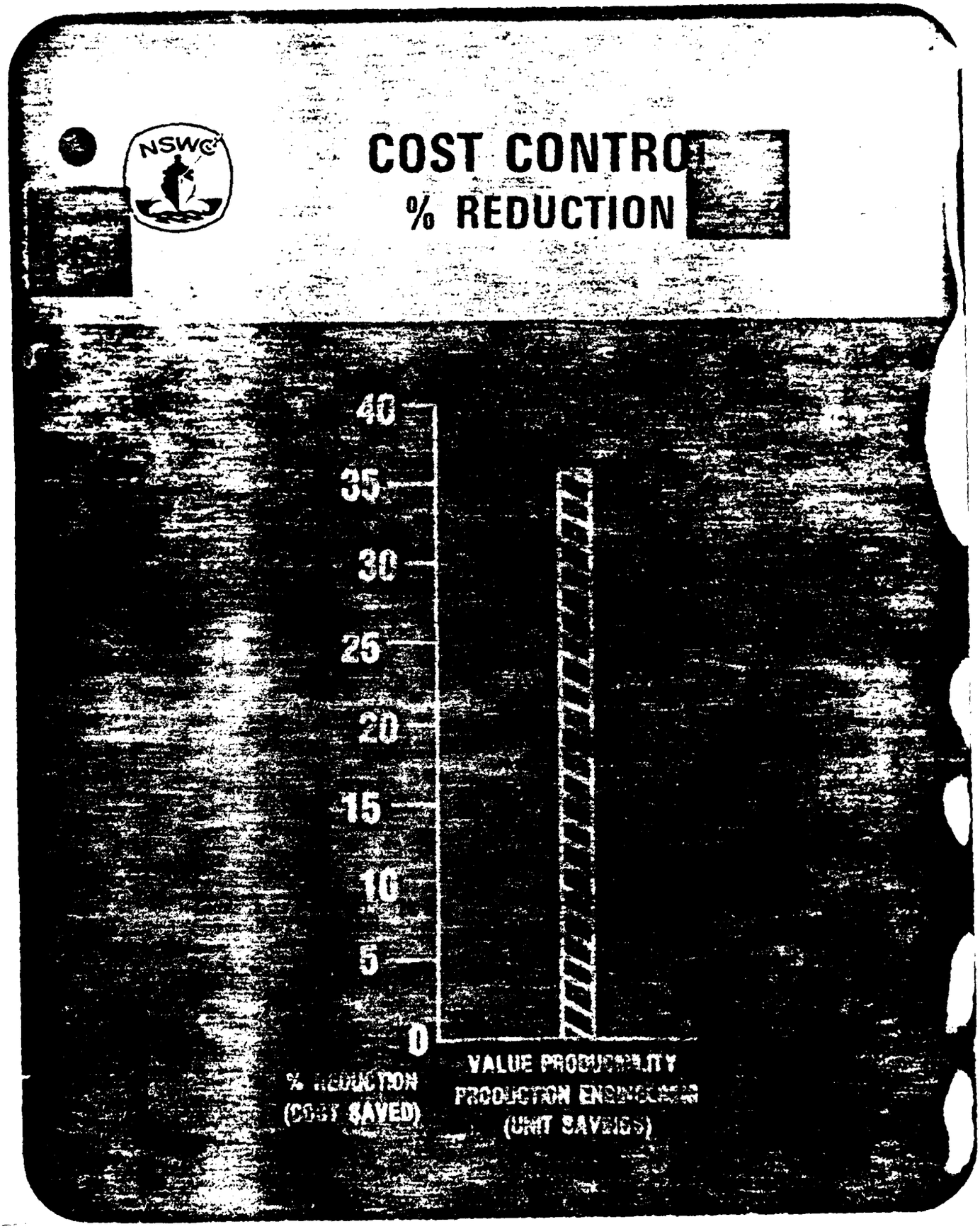


C.C.C DESIGN TO UNIT PRODUCTION COST

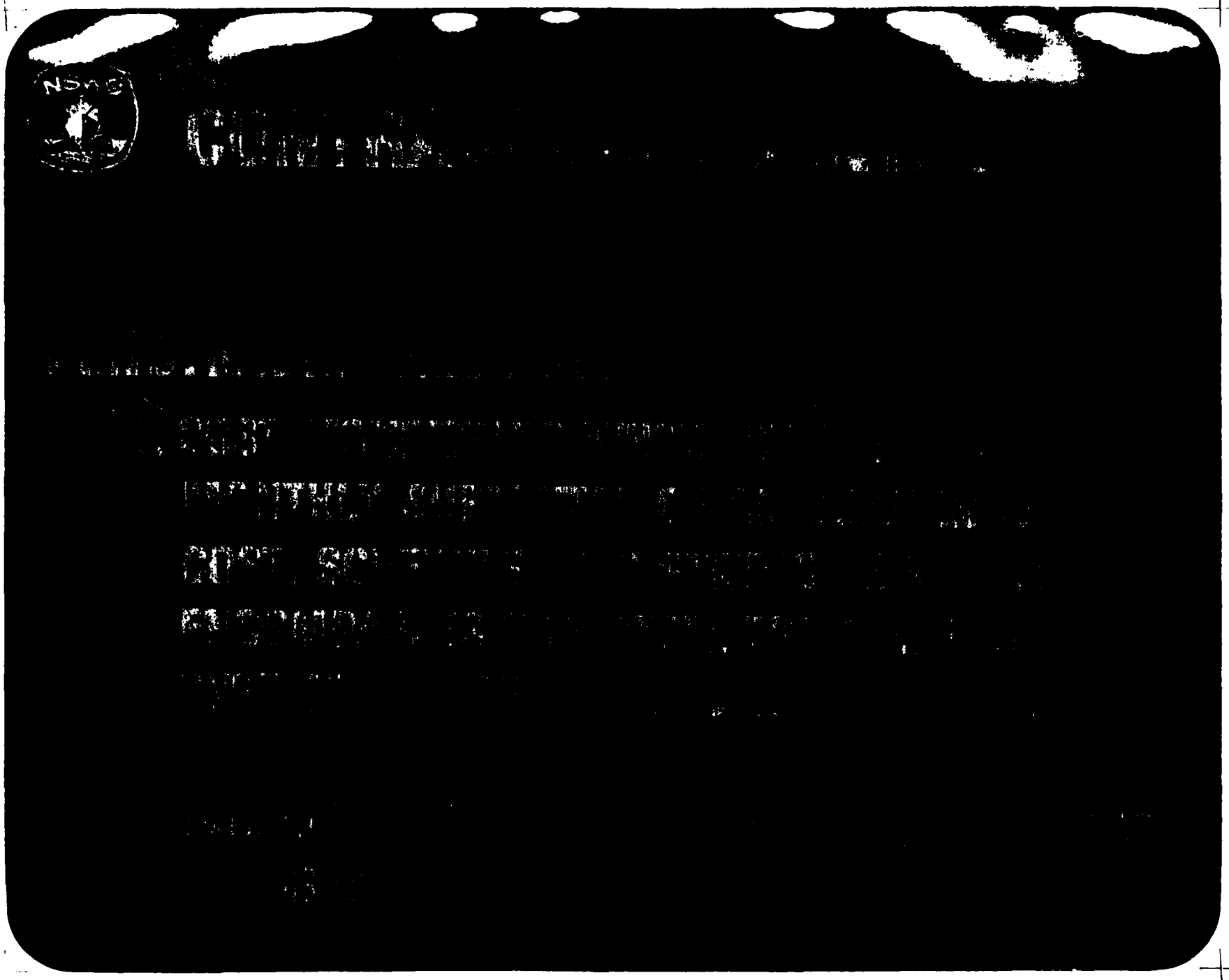


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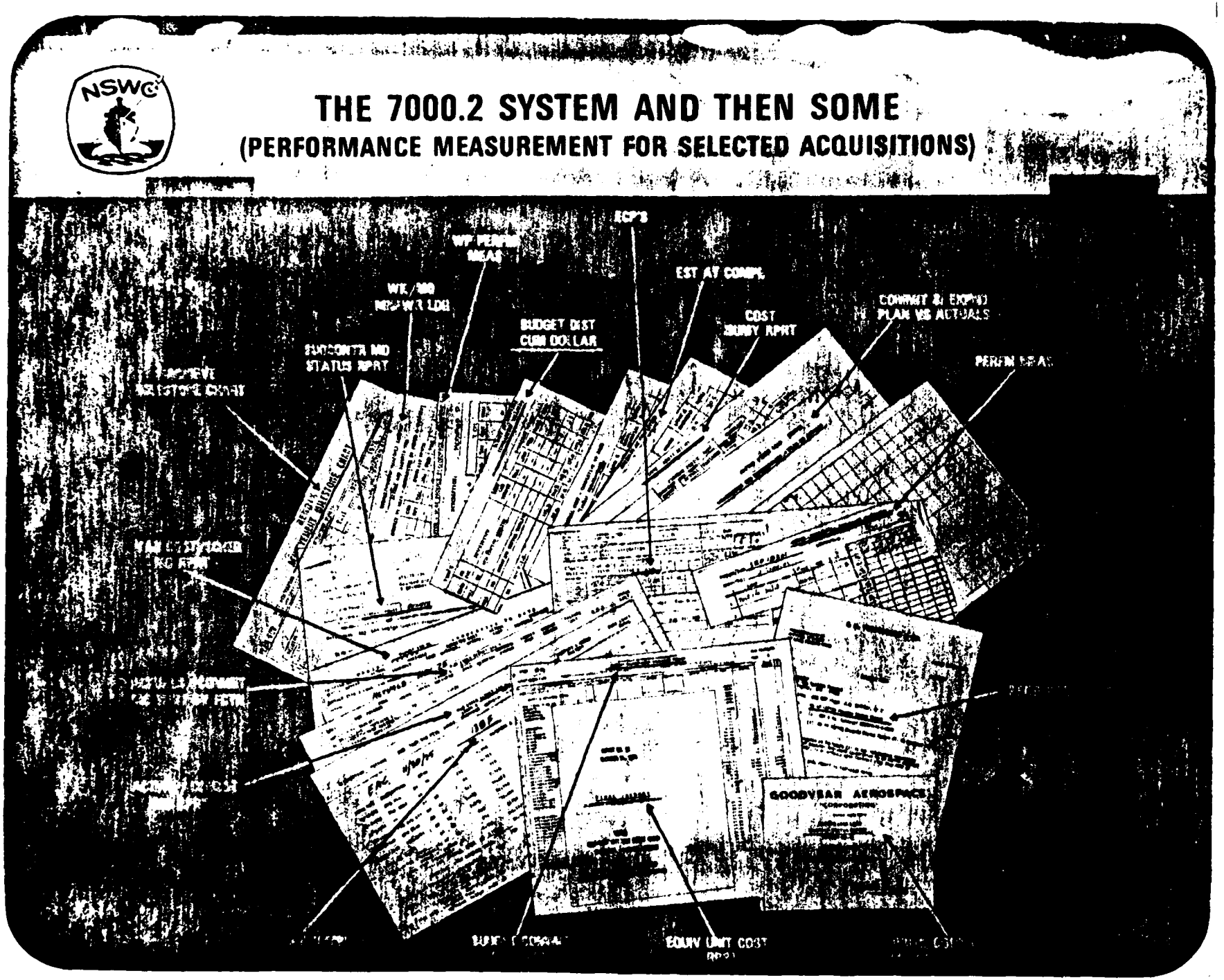
SAVINGS $/C90


NSWC
COST CONTRO
% REDUCTION
40
35
30
25
20
15
10
5
0
% REDUCTION
(COST SAVED)
VALUE PRODUCIBILITY
PRODUCTION ENGINEER
(UNIT SAVINGS)

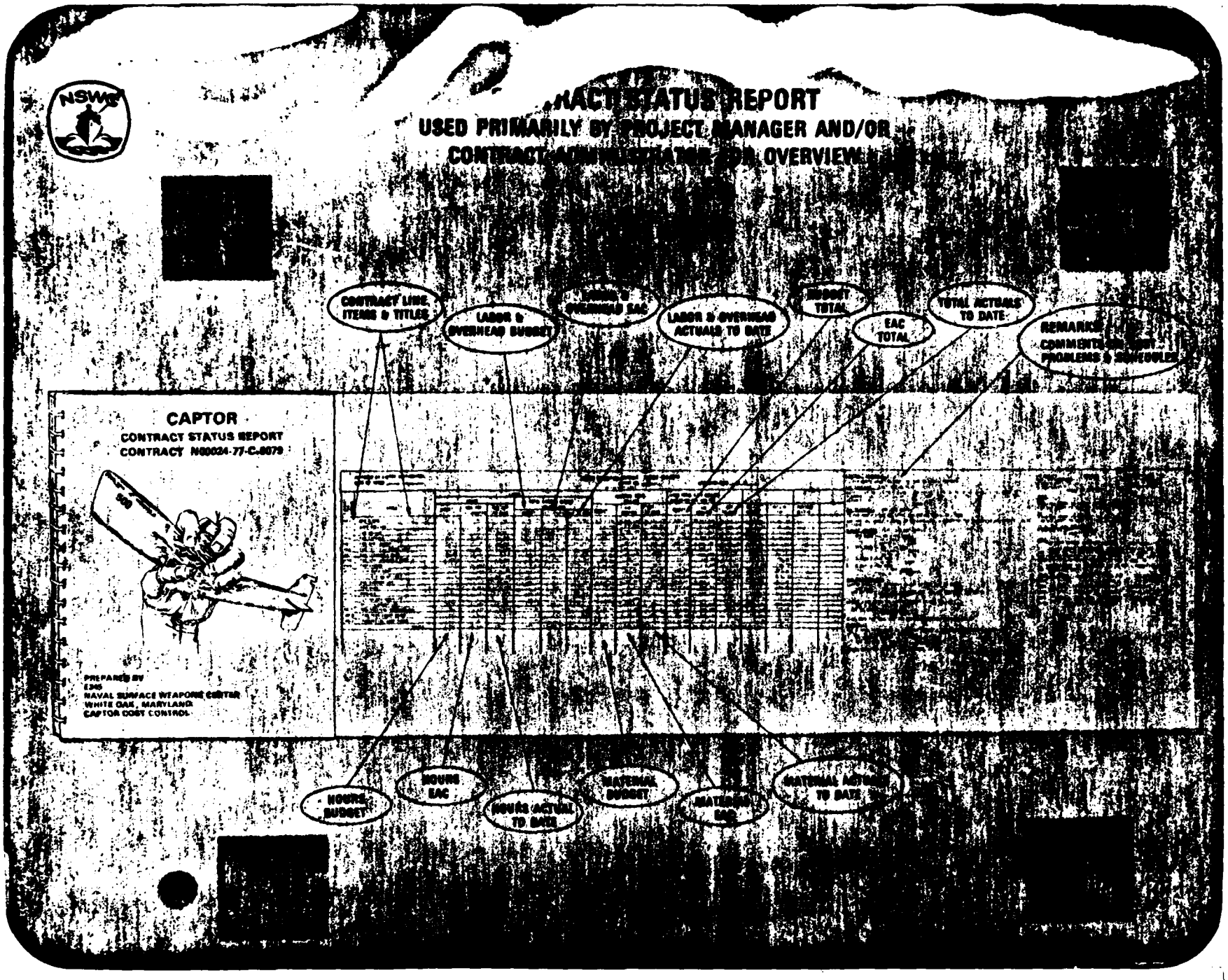
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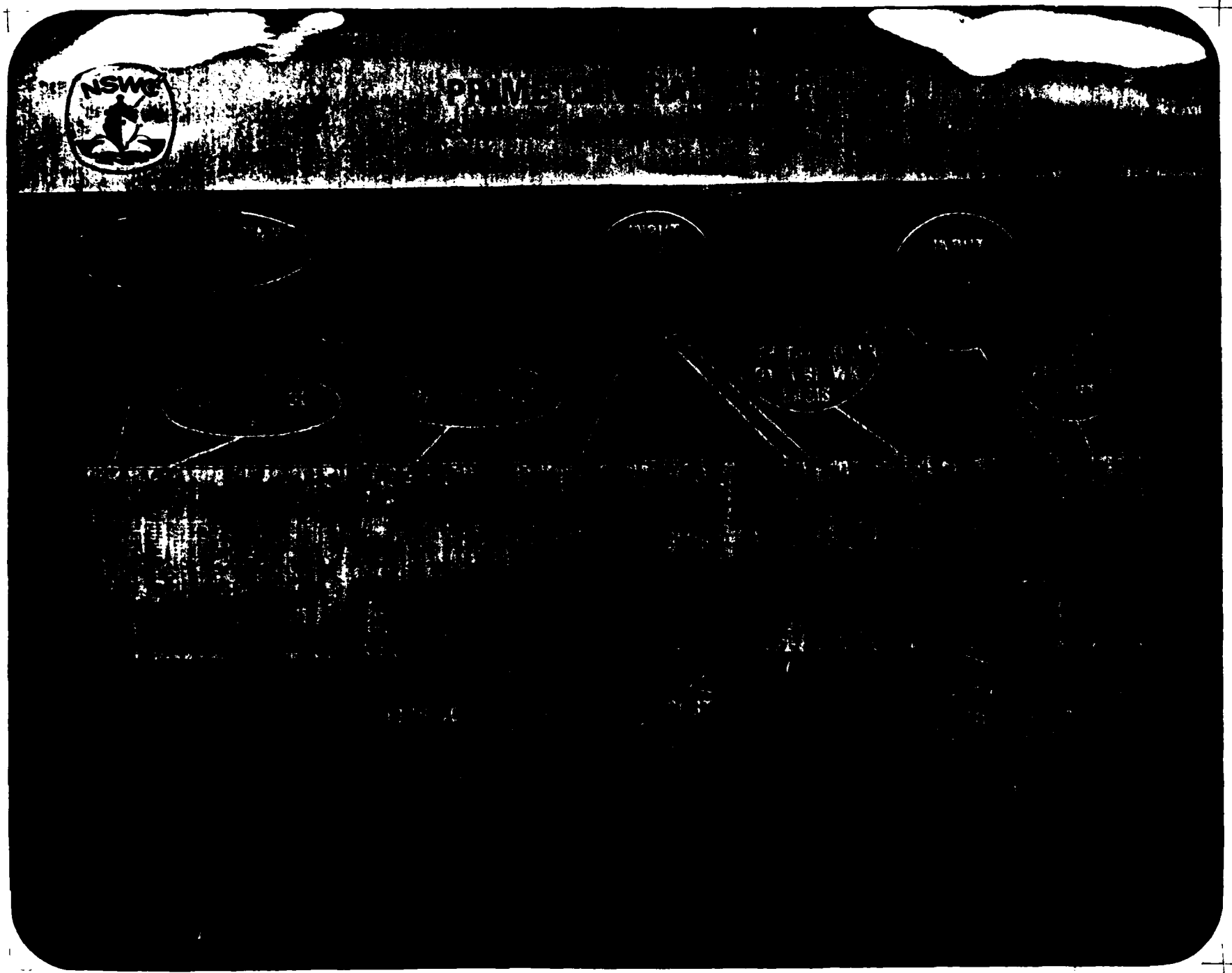
GEMINI


NSWC
THE 7000.2 SYSTEM AND THEN SOME
(PERFORMANCE MEASUREMENT FOR SELECTED ACQUISITIONS)
ECP'S
EST AT COMPL
COST
BUDGET DIST
CUM DOLLAR
GOODYEAR AEROSPACE
EQUIV UNIT COST

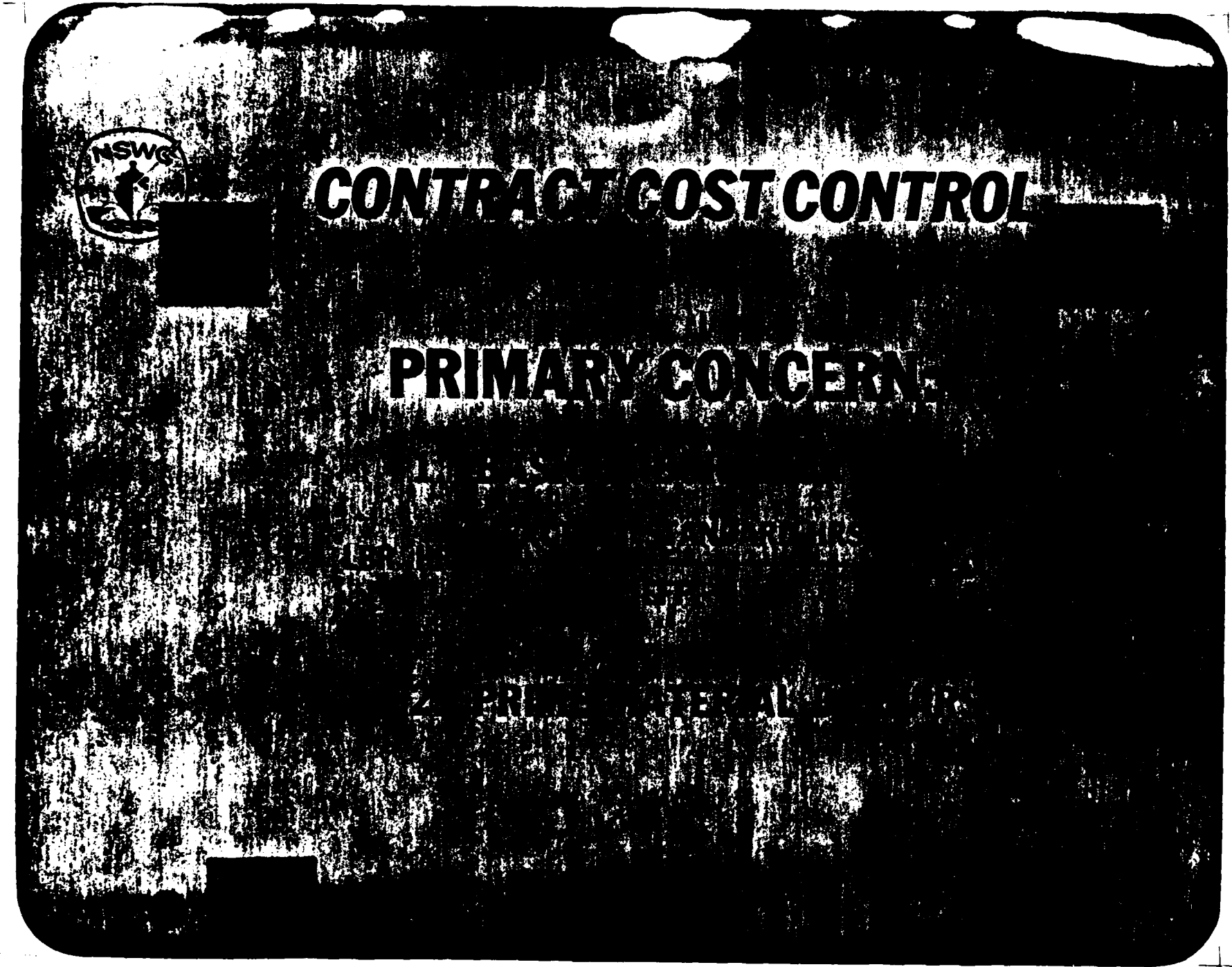
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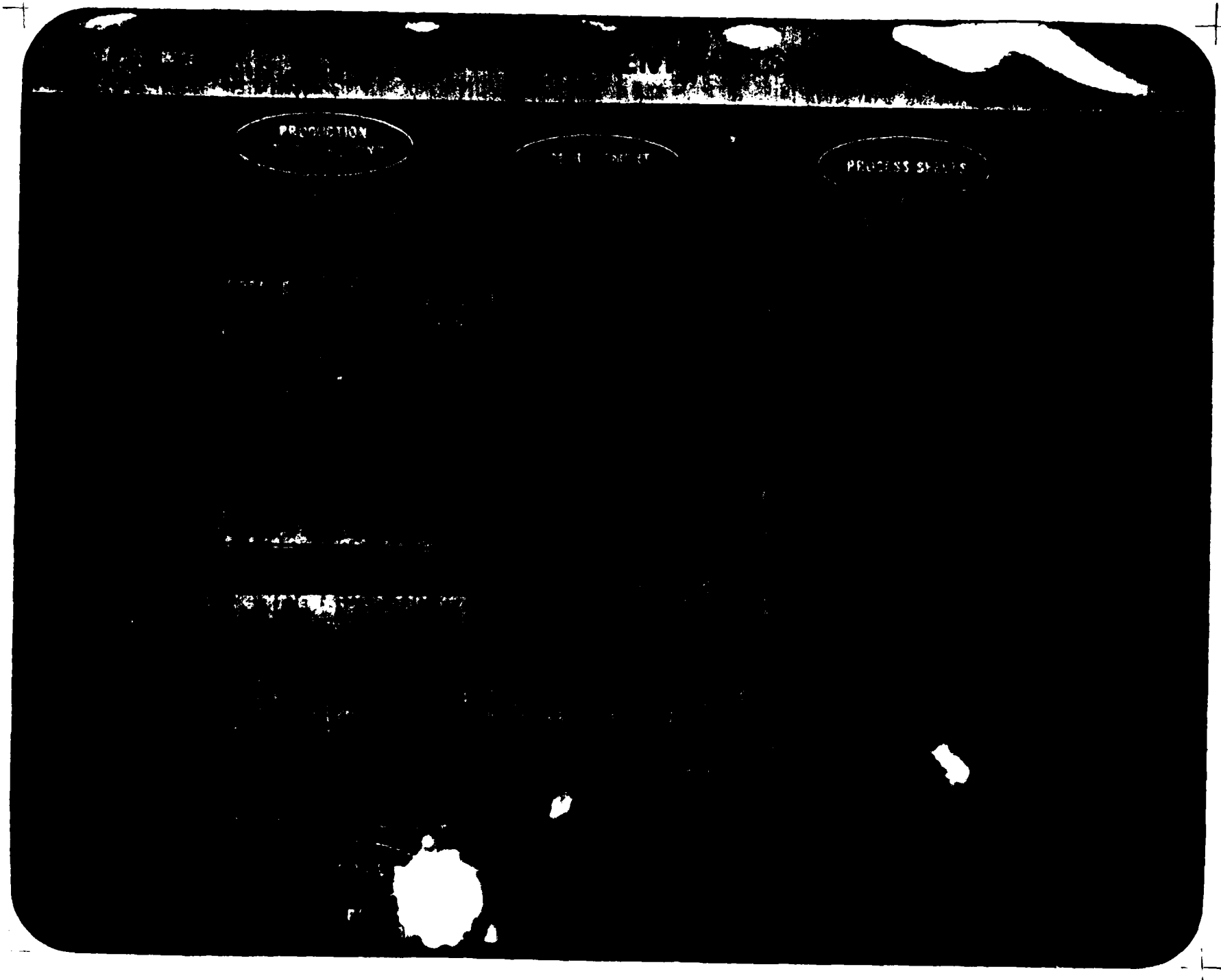

NSWC
CONTRACT STATUS REPORT
USED PRIMARILY BY PROJECT MANAGER AND/OR
CONTRACT
OVERVIEW
CONTRACT LINE ITEMS & TITLES
LABOR & OVERHEAD BUDGET
LABOR & OVERHEAD EAC
LABOR & OVERHEAD ACTUALS TO DATE
BUDGET TOTAL
EAC TOTAL
TOTAL ACTUALS TO DATE
REMARKS
CAPTOR
CONTRACT STATUS REPORT
CONTRACT N60024-77-C-8079
PREPARED BY
NAVAL SURFACE WEAPONS CENTER
WHITE OAK, MARYLAND
CAPTOR COST CONTROL
HOURS BUDGET
HOURS EAC
HOURS ACTUAL TO DATE
MATERIAL BUDGET
MATERIAL EAC
MATERIAL ACTUALS TO DATE

GEMINI

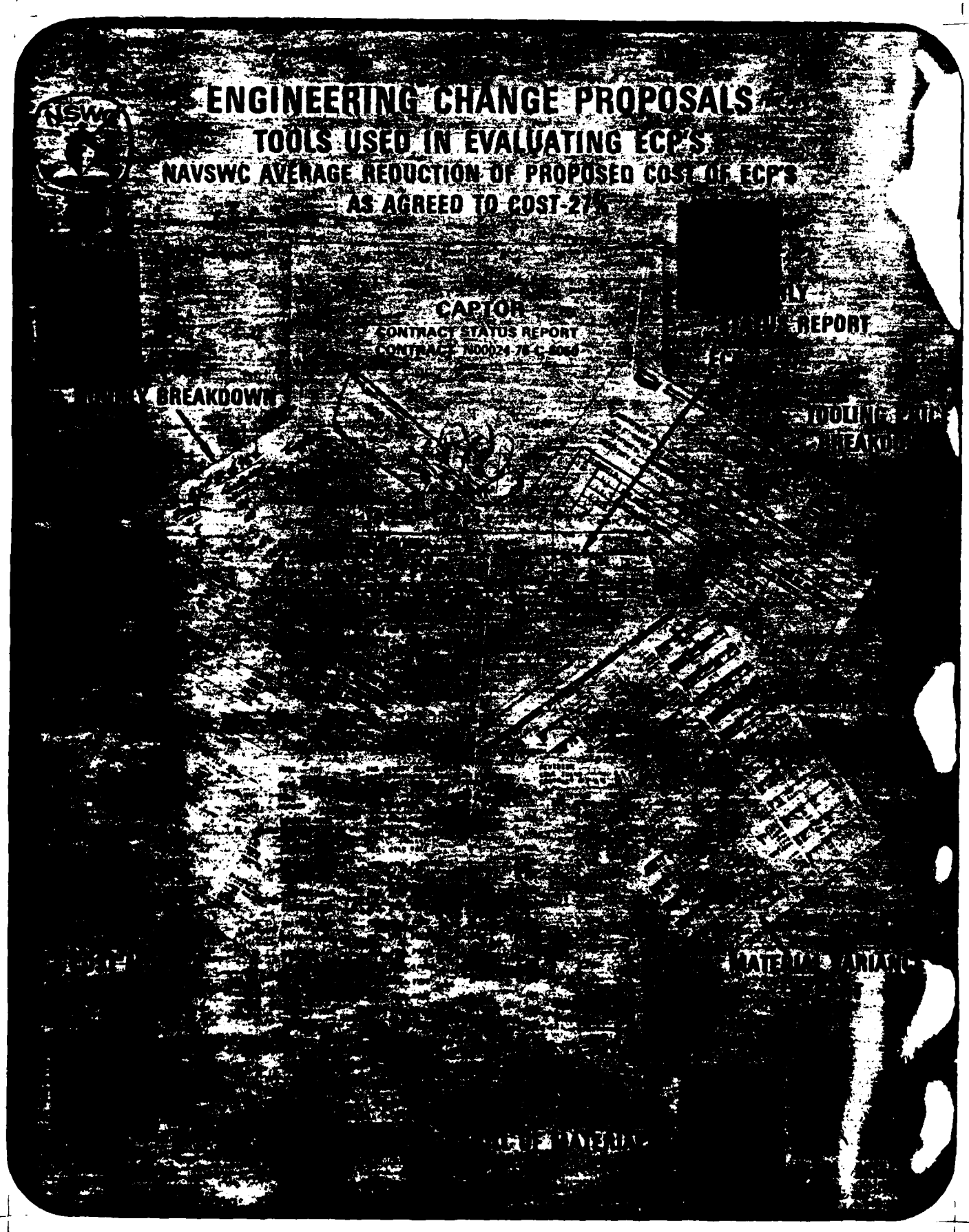


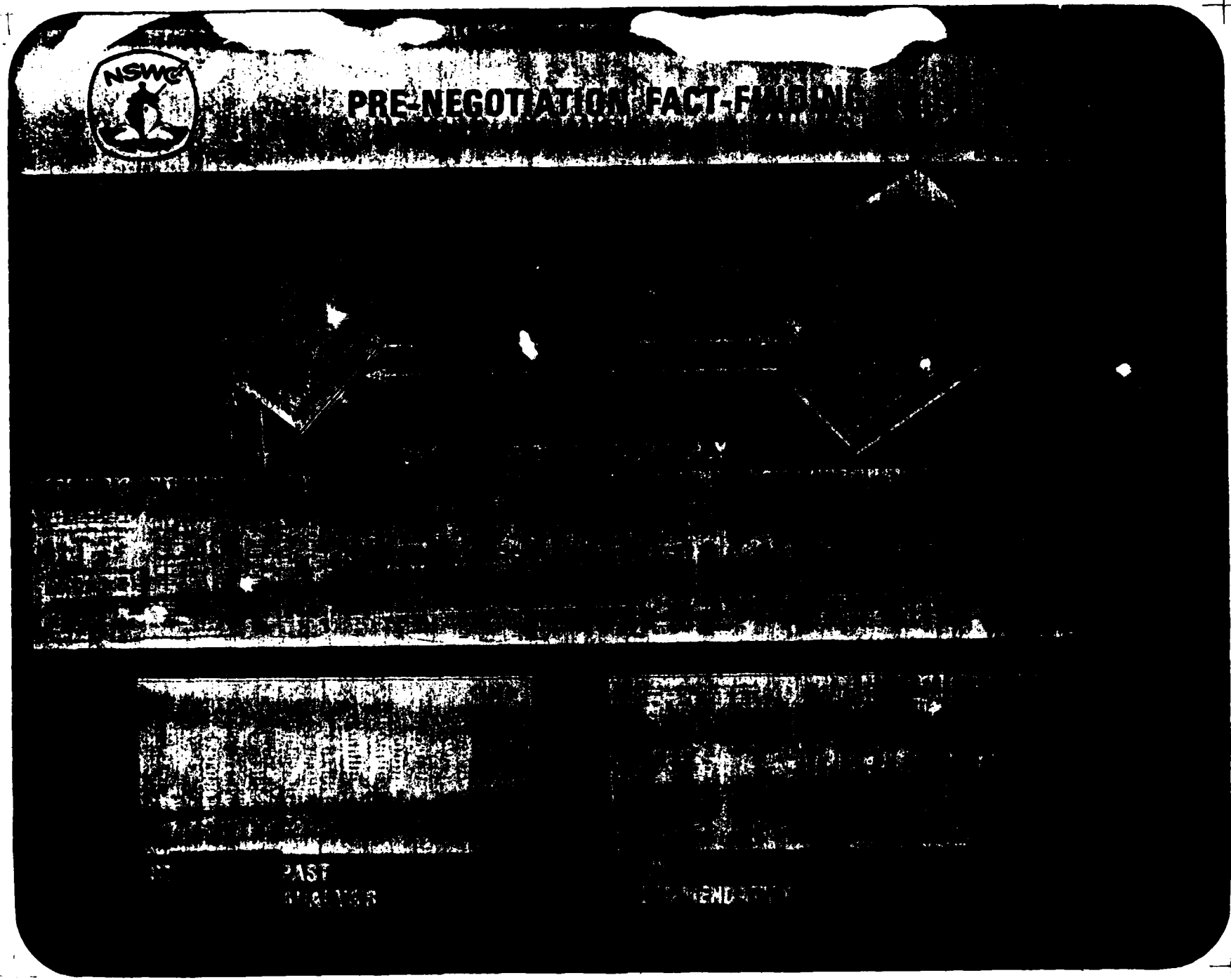
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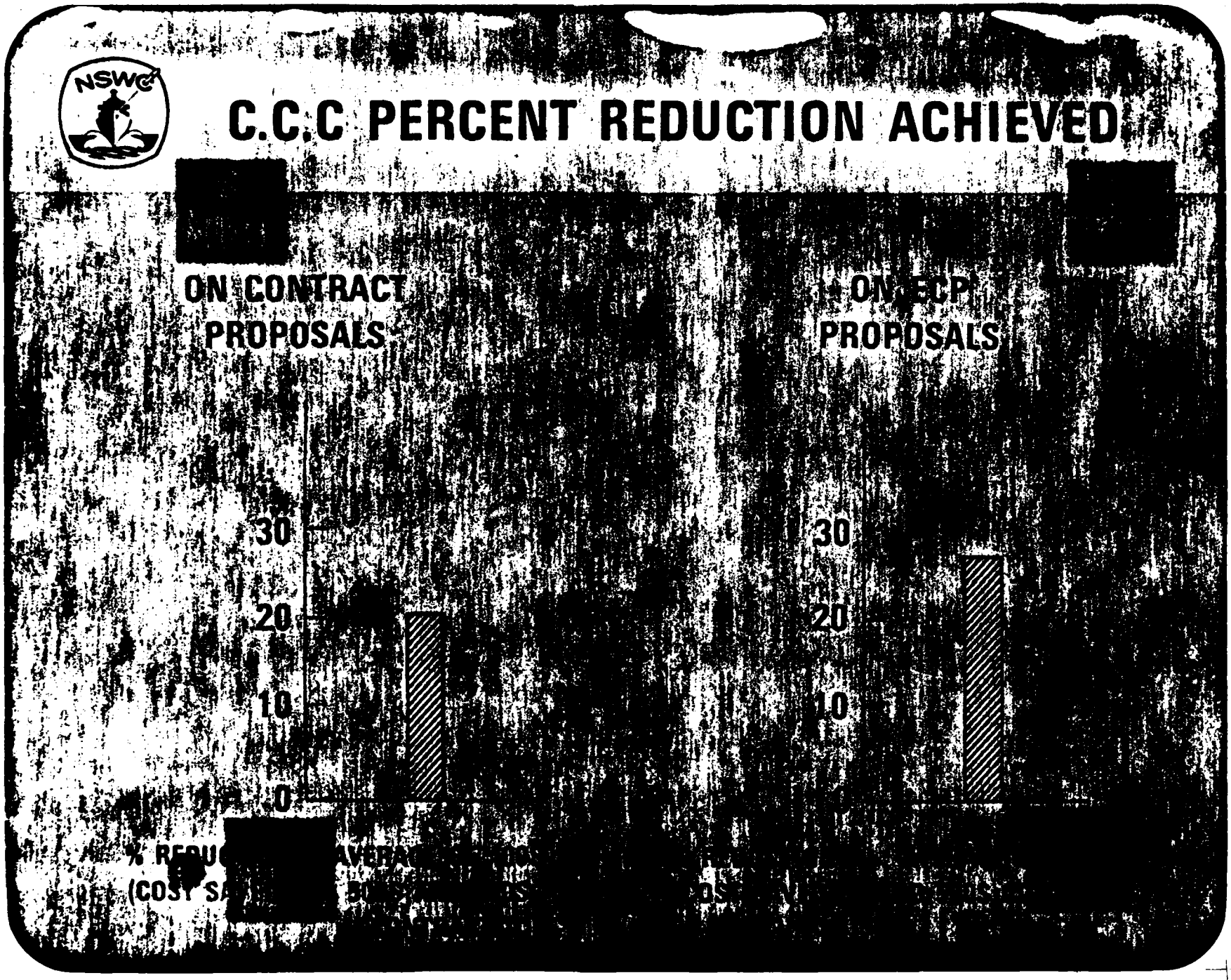

NSWC
CONTRACT COST CONTROL
PRIMARY CONCERN



GEMINI

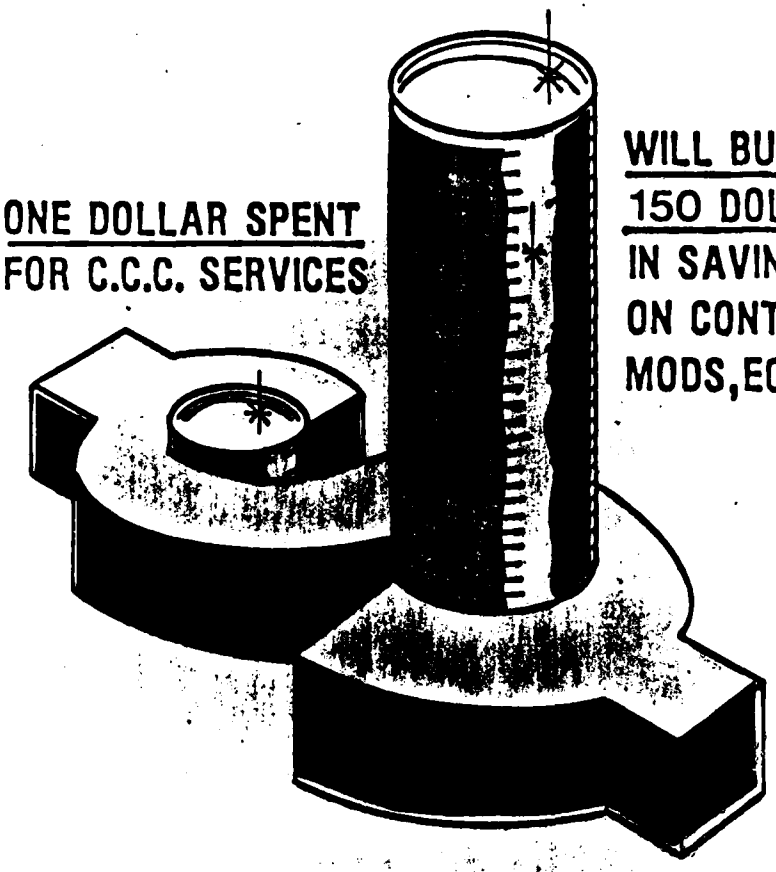

ENGINEERING CHANGE PROPOSALS
TOOLS USED IN EVALUATING ECP'S
NAVSWC AVERAGE REDUCTION OF PROPOSED COST OF ECP'S
AS AGREED TO COST-27%
CAPTOR
CONTRACT STATUS REPORT
REPORT
BREAKDOWN
GEMINI


NSWC
PRE-NEGOTIATION FACT-FINDING
PAST
GEMINI


C.C.C PERCENT REDUCTION ACHIEVED
ON CONTRACT PROPOSALS
ON ECP PROPOSALS
30
20
10
0
30
20
10

CONTRACT COST CONTROL IS GOOD BUSINESS

ONE DOLLAR SPENT FOR C.C.C. SERVICES



WILL BUY 150 DOLLARS IN SAVINGS ON CONTRACTS, MODS, ECP'S, ETC.

TO DATE

COST CONTROL CUMULATIVE SAVINGS FOR CODE 62Z LESS OUTLAYS ARE $60,000,000. TO PUT IT IN A DIFFERENT PERSPECTIVE THE [redacted] EQUATE TO THE COST OF 6 MK 13 MOD 4 GUIDED MISSILE LAU[redacted] SYSTEMS (482 DO[redacted] ARS)

COST CONTROL

1. WHERE CAN THIS TYPE OF SERVICE BE USED?

   THE COST CONTROL EFFORT CAN BE USED AT ANY POINT IN A PROGRAM WHERE A COST-TYPE CONTRACT EXISTS OR A RFP IS BEING ACTED UPON.

   A. DURING THE DEVELOPMENTAL PHASE, IT IS USED FOR THE ANALYSIS OF THE DESIGN FOR COST AND FOR AN INSTANTANEOUS DETAILED FINANCIAL STATUS OF EXPENDITURES VERSUS THE ESTIMATE (COST CONTROL);

   B. PRIOR TO CONTRACT NEGOTIATIONS, FOR DEVELOPMENT OF A "SHOULD COST," FOR EACH ITEM OR SYSTEM AND FOR SUPPLYING OF HISTORICAL COST DATA, and

   C. DURING PRODUCTION, FOR COST MONITORING AND TROUBLE SHOOTING.

DIVIDING THE MILITARY DOLLAR

II. SINCE LESS THAN A THIRD OF THE MILITARY DOLLAR PROVIDES FOR NEW WEAPONS AND HARDWARE, COST CONTROL HAS BECOME PARAMOUNT. WITH THE CURRENT 1982 PROCUREMENT BUDGET BEING OVER $65B EVEN A 1% SAVINGS WOULD BE $650M. THROUGH THE USE OF EFFECTIVE COST CONTROL AN EVEN GREATER PERCENT SAVINGS CAN BE REALIZED.

PROGRAM EVOLUTION

THE EVOLUTIONARY CYCLE FOR A PROGRAM CAN BE SUMMARIZED AS FOLLOWS:

1. SPECIFICATIONS - SET DOWN INITIAL SPECS
2. OUTLINE DRAWING - ROUGH DRAWING TO SHOW HOW PROGRAM HARDWARE WILL WORK
3. IDENTIFY COST DRIVERS AND REDUCE COST
4. 'NITIAL SET OF DRAWINGS - DRAWINGS TO BE USED FOR PRE-PRODUCTION BUILD
5. PRE-PRODUCTION BUILD - BUILD HARDWARE TO FIND PROBLEMS/FLAWS
6. FINAL SET OF DRAWINGS - REDRAW PLANS WITH ALL CORRECTIONS
7. FIRST PRODUCTION - BUILD HARDWARE

METHODS TO CONTROL COST

ONCE THE PROGRAM HAS BEEN APPROVED AND IS UNDERWAY, COSTS NEED TO BE CONTROLLED. SOME METHODS OF ACHIEVING THIS ARE:

1. DESIGN TO COST/DTUPC
2. VALUE ENGINEERING
3. MANUFACTURING PRODUCTION ENGINEERING
4. MAKE OR BUY
5. SHOULD COST
6. MULTI-YEAR BUY
7. ECONOMICAL PRODUCTION RATES
8. CONTRACT COST CONTROL

DEFINITION

CONTRACT COST CONTROL CAN BE DEFINED AS THE FUSING OF FISCAL ENGINEERING AND PRODUCTION ANALYSIS INTO AN ORGANIZED PROCEDURE IN ORDER TO ACQUIRE A SYSTEM, COMPONENT OR SERVICE FOR THE LEAST COST

COST CONTROL FUNCTION

HOW DOES THIS SERVICE ASSIST OTHER PROGRAM FUNCTIONS?

THE COST CONTROL ANALYST SERVES AS A BRIDGE FOR ALL PROGRAM PERSONNEL, BECAUSE THE COST CONTROL ANALYST WORKS WITH ALL LEVELS OF THE CONTRACTOR STAFF. THIS WORK CONSISTS OF PROBING, ANALYZING AND INVESTIGATING ALL FACETS OF THE CONTRACTOR'S OPERATIONS. THEREBY, DEVELOPING INTIMATE SOURCES OF INFORMATION AND DETAILED KNOWLEDGE OF THE CONTRACTOR'S OPERATING SEQUENCES. PROBLEMS ARE DETECTED EARLY AND REMEDIAL ACTIONS TAKEN TO AVOID DELAYS AND COST OVERRUNS. THIS SERVICE PROVIDES THE FOLLOWING SUPPORT:

1. FOR THE PROGRAM MANAGEMENT: ON SITE SURVEILLANCE TO AN EXTENT, THAT THEIR MANAGEMENT RESPONSIBILITIES WOULD PRECLUDE AND WITH A PROGRAM TECHNICAL POINT OF VIEW NOT NORMALLY ACHIEVED BY A NAVPRO, AFPRO OR DCAS.
2. FOR THE CONTRACTING OFFICER AND NAVPRO'S TECHNICAL ADVICE: CONTRACTING OFFICERS CANNOT BE EXPECTED TO KNOW THE RELATIVE COST OF VARIOUS PRODUCTION TECHNIQUES.
3. FOR ENGINEERING: QUICK-RESPONSE COST AND PRODUCTION INFORMATION CONCERNING PROPOSED CHANGES, SCHEDULING AND FABRICATION PROBLEMS.

FUNCTIONAL SERVICES FOR PROGRAM MANAGEMENT

THESE SERVICES INCLUDE:

1. EVALUATION OF:
   - A. ENGINEERING SUPPORT HOURS.
   - B. PRIME CONTRACTOR ESTIMATES.
   - C. IMPROVEMENT CURVES.
   - D. COST INCREASES DUE TO CHANGES IN PROCUREMENT AMOUNTS TO ENSURE THE MOST EFFECTIVE USE OF THE NAVY PROCUREMENT DOLLAR.
2. PLOTTING OF COST CURVES ON UNIT COST TO MAKE PREDICTIONS.
3. ATTEND DESIGN OR MANUFACTURING PROBLEM MEETINGS TO KEEP CURRENT ON CONTRACT PROBLEMS.
4. ESTIMATE MANNING TO TRACK CONTRACT PROGRESS AND SUCCESS.
5. REPORT ON COST, SCHEDULE, AND CONTRACTOR PROGRESS TO NAVY PROGRAM MANAGERS TO ALLOW FOR MORE INFORMED MANAGEMENT DECISIONS.

FUNCTIONAL SERVICES FOR CONTRACTS

THESE SERVICES INCLUDE:

1. EVALUATE COSTS ASSOCIATED WITH CHANGES IN SCHEDULE.
2. ANALYZE RFQ'S BEFORE AND/OR AFTER CONTRACTS ARE PLACED.
3. MONITOR ACTUAL VERSUS BUDGETED PROGRAM COST.
4. ANALYZE AND MAKE RECOMMENDATIONS ON CONTRACTOR COST PROPOSALS.
5. REPORT ON COST, SCHEDULE AND CONTRACTOR PROGRESS.

USE OF THE ABOVE SERVICES ALLOWS FOR BETTER INFORMED NAVY POSITIONS IN CONTRACT NEGOTIATIONS.

FUNCTIONAL SERVICES FOR ENGINEERING

FIRST, THERE MUST BE A PRODUCT FAMILIARIZATION PHASE WHERE THE COST CONTROL ANALYST ANSWERS FOR HIMSELF THE WHAT, HOW, WHERE, AND WHY OF THE SYSTEM. THAT IS: WHAT IS THE SYSTEM SUPPOSE TO DO?

WHERE WILL IT DO IT?

HOW WILL IT DO IT?

HOW LONG MUST IT DO IT?

WHY MUST IT BE DONE?

HOW WILL IT BE MADE SO IT CAN DO IT?

AFTER ALL THE "DO-ITS" ARE UNDERSTOOD, AN IN-DEPTH ANALYSIS OF PRODUCTION PROCESSES CAN BE EMBARKED UPON IN ORDER TO IDENTIFY AREAS OF HIGH COST AND TO DIRECT EFFORTS TOWARD HARDWARE COST REDUCTION. INITIAL EFFORTS ARE CONCENTRATED ON THOSE AREAS SHOWING THE GREATEST POTENTIAL FOR YIELD.

1. ANALYSIS OF DESIGN FOR COST REDUCTION.
   - A. CAN PARTS BE DELETED?
   - B. CAN PART BE SIMPLIFIED?
   - C. CAN MATERIAL BE CHANGED?
   - D. CAN TOL AND/OR FINISHES BE RELAXED?
   - E. CAN PARTS BE COMBINED?

FUNCTIONAL SERVICES FOR ENGINEERING (CONT'd)

2. ANALYSIS OF FABRICATION PROCESSES

   A. REVIEW MAKE OR BUY DECISIONS

   B. HOW MANY SETUPS ARE PLANNED

      (1) HOW DO THEY EFFECT QA

      (2) HOW DO THEY IMPACT SETUP TIME

   C. HOW WILL MACHINE LOADING IMPACT SCHEDULE

      (1) ARE MACHINE OVERLOADED (DELAYS)

      (2) ARE COSTLY FAB TECH BEING USED

      (3) REVIEW PLANNING SHEETS

      (4) REVIEW PROCESSING SHEETS

   D. CAN A LESS EXPENSIVE PROCESS (CASTING, FORGING, ETC.) BE USED

THE PRODUCTION PROCESSES STUDY, ON A NAVY MINE LASTED FOR SIX MONTHS AND REDUCED THE ESTIMATED WEAPON UNIT COST BY 30%, IT WAS A TEAM EFFORT AND UTILIZED A FUTURE MEMBER OF THE COST CONTROL TEAM, PRIME CONTRACTOR AND NAVY DESIGNERS, PRODUCTION SPECIALISTS, QA PERSONNEL, VENDORS AND ANYONE ELSE THAT COULD CONTRIBUTE POSITIVELY TO THE EFFORT. SUBSEQUENT COST MONITORING WAS DONE, AT THE DIRECTION OF, AND REPORTING TO THE PROGRAM MANAGER.

CONTRACT COST CONTROL D.T.U.P.C. IN FULL VIEW

EACH OF THE COMPONENTS LISTED WERE PRODUCED INDIVIDUALLY.

C.C.C. DESIGN TO UNIT PRODUCTION COST

SHOWING SAVINGS ACHIEVED BY ONE BASIC FORGING AND THEN SEPARATING THE PARTS BY CUTTING AND FINISHING WITH A FEW MACHINING OPERATIONS.

C.C.C. DESIGN TO UNIT PRODUCTION COST

THE COMPONENT AS DESIGNED BY THE CONTRACTOR WITH HARD WIRING.

C.C.C. DESIGN TO UNIT PRODUCTION COST

THE SAME COMPONENT AFTER BEING REDESIGNED BY COST CONTROL USING MULTILAYER PC BOARDS.

(TWO (2) VIEWS OF DESIGN CHANGE IMPROVEMENT)

BOTTOM SAMPLE IS BEFORE AND TOP IS AFTER COST CONTROL REDESIGNED THE PART. TOP SAMPLE WAS CAST WHILE BOTTOM WAS WELDED. NEW PART HAS HOLES TO REMOVF CORE. ALTHOUGH WIRES RUN THROUGH TUBE, THE SLOTS DO NOT ADVERSELY AFFECT USAGE.

(TWO (2) VIEWS OF QUARTERBAND FOR PARACHUTE RELEASE)

BOTTOM QUARTERBAND IS RESULT OF D.T.U.P.C. TO PRODUCE IT AS A SINGLE UNIT BY FORGING RATHER THAN PIECE WELDING AS HAD BEEN THE CONTRACTOR'S PRACTICE.

COST CONTROL % REDUCTION

APPROXIMATELY A 36% REDUCTION IN PRODUCTION ENGINEERING COSTS RESULTED FROM THE OVERALL USE OF COST CONTROL METHODS. THIS RESULTS IN MORE VALUE FOR EACH NAVY PROCUREMENT DOLLAR.

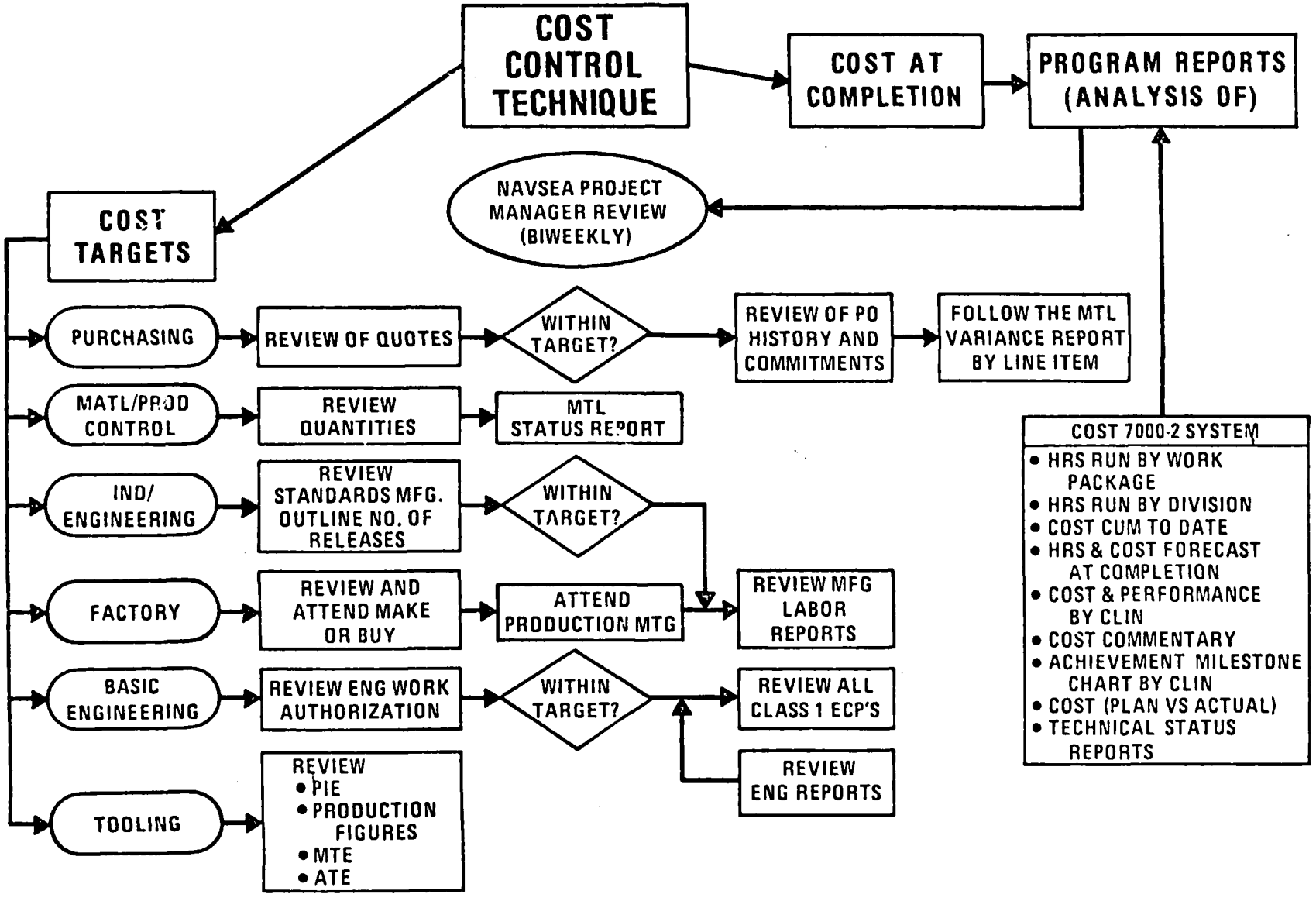
CONTRACT COST CONTROL

FUNCTION IN PRODUCTION

1. COST MONITORING - CONSTANT ANALYSIS OF CONTRACTORS COST, SCHEDULE, AND STATUS REPORTS AND A MONTHLY GENERATION OF AN INDEPENDENT REPORT ON THE CONTRACTORS COST, SCHEDULE, AND STATUS INCLUDING THE DOD 7000.2 REPORTING CRITERIA.
2. BEFORE ANY AND ALL CONTRACT CHANGES A COMPLETE EVALUATION OF IMPACT IS CONDUCTED AND A PRE-NEGOTIATION OF THE CONTRACT CHANGES IS PERFORMED.

FLOW OF INFORMATION

INFORMATION FLOW AND REVIEW



15 A

THE 7000.2 SYSTEM AND THEN SOME

CONTRACTOR REPORTING

THE VOLUMINOUS AMOUNT OF 7000 SERIES DATA IS SCATTERED. THE CONTRACTOR IS NOT REQUIRED TO REPORT IN DETAIL THE ACTUALS AGAINST THE ESTIMATES; HE MAY REPORT BY WORK PACKAGE STRUCTURES ONLY. THE CONTRACT COST CONTROL REPORT, ON THE OTHER HAND, TRACKS COST WITHIN WORK PACKAGE AND BY JOB ORDER NUMBER. THESE DATA ACTUALS ARE INSTANTANEOUSLY COMPARED AGAINST THE NEGOTIATED ESTIMATES BY HOUR, AND PERCENT COMPLETION. OUR SYSTEM TRACKS AGAINST THE ESTIMATE AND BREAKS DOWN EACH COMPONENT BY LABOR AND MATERIAL.

CONTRACT STATUS REPORT

A TYPICAL CONTRACT STATUS REPORT PROVIDED THE PROJECT MANAGER, PROVIDES THE FOLLOWING ITEMS IN A ONE PAGE, READILY ASSIMILATED FORMAT:

- CONTRACT LINE ITEM AND TITLES
- LABOR AND OVERHEAD BUDGET
- LABOR AND OVERHEAD EAC
- LABOR AND OVERHEAD ACTUALS TO DATE
- BUDGET TOTAL
- EAC TOTAL
- TOTAL ACTUALS TO DATE
- HOURS BUDGET
- HOURS EAC
- HOURS ACTUAL TO DATE
- MATERIAL BUDGET
- MATERIAL EAC
- MATERIAL ACTUALS TO DATE
- REMARKS (COMMENTS ON COST PROBLEMS AND SCHEDULES)

PRIME CONTRACTOR

(CONTRACT LINE ITEM XXXX)

THE ONE PAGE REPORT ON A PRIME CONTRACTOR IS SIMILAR TO THE CONTRACT STATUS REPORT WITH THE DIFFERENCES BEING MAINLY IN THE TYPES OF ITEMS. THESE ITEMS ARE:

WORK BREAKDOWN STRUCTURE LEVEL

JOB CHARGE #

LABOR HOURS ESTIMATE

HOURS ACTUALS

INPUT WEEKLY AND/OR MONTHLY

INPUT MONTHLY STATUS REPORT AND THE TECHNICAL REPRESENTATIVE INTERFACE WITH THE CONTRACTOR ON A BI-WEEKLY BASIS

INPUT REQUIREMENTS AND MILESTONE MONTHLY REPORT

LABOR COST ESTIMATE

LABOR COST ACTUALS

MATERIAL COST ESTIMATES

MATERIAL COST ACTUALS

ESTIMATE OF TOTAL COST TO NAVY

ACTUAL COST TO NAVY

CONTRACT COST CONTROL

PRIMARY CONCERN:

1. BASIC LABOR HOUR

   $$\text{LABOR HOUR} = \frac{\text{FACTORY STANDARD HOURS}}{\text{EFFICIENCY}} \times \text{LED}$$

   (THE LED REPRESENTS LOSSES, ERRORS AND DEFECTS)

2. PRIME MATERIAL DOLLARS

EFFECTIVE COST CONTROL CENTERS AROUND AND IS BASED ON THESE TWO AREAS. THE MAIN PURPOSE OF CONTRACT COST CONTROL IS TO OBTAIN THE BEST POSSIBLE RETURN ON NAVY PROCUREMENT DOLLARS BY FINDING MORE EFFICIENT METHODS AND CORRECTING CONTRACTOR ERRORS.

MANAGEMENT TOOLS

UNIQUE MANAGEMENT TOOLS

THE COST CONTROL TEAM ALSO PROBES AND KEEPS AN EYE ON MANY DATA ITEMS BEYOND 7000 SERIES REQUIREMENTS. FOR EXAMPLE, ON A CURRENT CONTRACT, DOCUMENTATION AND ITS STATUS ARE MAINTAINED FOR ALL TOOLING, PIE, AND MTE, THUS PROVIDING A BASIS FOR EVALUATING CONTRACT COST INCREASES ~~CLAIMS~~, DUE TO TOOLING, AND THE # R.O.C.'S ~~CHANGES CAUSED BY PROPOSED HARDWARE CHANGES~~. THE MANAGEMENT TOOLS INCLUDE:

- PRODUCTION STATUS MEETING REPORTS
- IMPROVEMENT CURVES
- PROCESS SHEETS
- COST MODEL
- FABRICATION WEEKLY MANPOWER REPORTS

ENGINEERING CHANGE PROPOSALS

BY USING THE AVAILABLE ECP EVALUATION TOOLS C.C.C. WAS ABLE TO REDUCE ECP COSTS. MANY DOCUMENTS ARE STUDIED TO EVALUATE ECPS. THESE INCLUDE:

- HOURLY BREAKDOWN
- MONTHLY STATUS REPORT
- TOOLING PRICE BREAKDOWN
- MATERIAL VARIANCE REPORTS
- COST MODEL
- BILL OF MATERIAL

PRE-NEGOTIATIONS FACT-FINDING

1. THE CONTRACT COST CONTROL ASSISTS PROGRAM MANAGEMENT BY REVIEWING THE CONTRACTORS PROPOSAL IN ORDER TO ESTABLISH THE NAVY'S POSITION ON A "SHOULD COST" FOR THE SYSTEM. "SHOULD COST" IS THAT COST WHICH WOULD DELIVER TO THE NAVY "COST EFFECTIVE" HARDWARE OF A GIVEN DESIGN AND IS BASED ON AN IN-DEPTH PRODUCTION PROCESS ANALYSIS. THE ANALYSIS INCLUDES SUCH THINGS AS EVALUATION OR DEVELOPMENT OF LEARNING CURVES, EVALUATION OF MATERIAL AND LABOR COST BY COMPARISON WITH HISTORICAL DATA. AN ANALYSIS OF LABOR COST FROM SEVERAL POINTS OF VIEW SUCH AS:
   A. COMPARING PROPOSED LABOR HOURS WITH PRIOR CONTRACT LABOR HOURS
   B. EVALUATING THE EFFECT OF PRODUCT IMPROVEMENTS ON LABOR HOURS
   C. A STATISTICAL ANALYSIS OF SUPPORT HOURS VERSUS FABRICATION HOURS
   D. ANALYSIS OF PURCHASING (QUANTITIES AND COST) REVIEW VENDOR QUOTES
      (1) ARE THEY CURRENT
      (2) ARE THEY REASONABLE

IN SUMMATION,

~~IN CONCLUSION:~~ IT MUST BE SAID THAT BASED UPON THE ~~RESULTS~~ ACHIEVED WITH THIS TECHNIQUE, ONE MAY REASONABLY ASSUME THAT SIMILAR RESULTS ARE POSSIBLE ON OTHER [redacted] PROGRAMS. ~~THIS RETURN ON INVESTMENT (R.O.I.) FOR A CONTRACT COST CONTROL TEAM WILL JUSTIFY MANY TIMES OVER ITS EXISTANCE.~~

THE BENEFITS TO BE GAINED ARE CONSIDERABLE AND IN TODAYS MONEY ENVIRONMENT CANNOT BE OVERLOOKED.

COST DATA RESEARCH

Edward Flanagan

The scope and complexity of modern helicopter technology greatly complicates the prepration of advanced helicopter weapon system cost estimates. The increasing rate of technological change tends to degrade the relevance of historical data and the validity of cost estimates based on it. This requires cost analysts improve their understanding of the total implications of new technology and properly reflect these implications in their analyses. This is a difficult, detailed and challenging task, requiring sigaificant and continuous data research efforts.

Recognizing that research is the principal source of innovation and new methodology, most cost data research effort has, as in the past, been designated as a major action item, and necessitates the development of a formal plan. Our overall guidelines that have been developed to support this research plan are designed to benefit those performing the research as well as to avoid duplication of prior research work. In addition, the overall plan provides a basis for the additional development and selective expansion of the command cost data base. In our analyses we are continually grasping for more complete definition but, in this case, lets consider the research activity in broad terms. The research that is routinely necessary to satisfactorily complete a task i.e., a BCE or an ICE, is not included in this concept.

This plan records the past, describes the present and predicts projected research and methodology efforts of the analytical community to meet the challenges forthcoming. Covered is the development of computerized cost models, CERs, cost factors, inflation indices, and general research of cost data and methodology. Throughout the plan, emphasis is placed on the importance that adaptability and use of adjustments play in the application of these cost estimating tools.

The purposes of our research and publication efforts are oriented towards the support/service of our "customers," the timely preparation of utility documents, and the reflection of the increasing rate of technological changes on work as tasked by the higher command levels. Our projects are oriented towards are actual experiences in such areas as computer models, DRAs, DTC, TRACE, etc. These "real-world" projects are used to record, expand and cross-fertilize the expertise of analytical skills assigned to major Army programs; these work assignments are tailored toward analytical backgrounds and work experiences, toward lessons learned aspects, and toward creativeness (springboard) necessary to address anticipatory applications to near-future programs.

The major constraints to our research efforts are certainly not new. These are the constant lack of personnel resources and the continuous stream of taskings that are generally oriented toward preparation of cost estimates on a crash basis. Consequently, an orderly and structured process or procedure for cost analysis operations and for in-depth research is somewhat difficult to maintain. For a number of years, an effort has been directed, on a limited basis, to a number of pertinent research projects. Desires for in-depth mathematical and statistical models have not been fulfilled due to inadequate staffing, quick-reply priorities and the orderly inter- and intra- organizational flow of data. The purpose of this

formal plan is to assist in directing the necessary research efforts toward determining the judicious expenditure of analytical resources. All reorganizations (like most reorganizations, past and future) do not really eliminate any research functions or requirements.

As part of the research effort, time consideration is given to the numbers, the varieties and the varied sources of documents that pass through the organization. In a year's time, 250 - 400 documents are received/reviewed from such diverse sources as the disciplines of various professional groups, industry, NASA, other MACOMs, "think-tanks," government reports index, Navy and Air Force, the National Technical Information Service (NTIS) of the Department of Commerce, the Department of Labor, financial institutions such as the Federal Reserve Bank and Chase-Manhattan Bank and requested documents from the data banks of the DTIC and DLSIE. Added to these are such management-type publications such as the Sloan Management Review, the Harvard Business Review, newsletters from assorted institutes and professional societies and the various publications from the American Management Association. Many of these documents are eliminated from our specific application(s) by only a cursory examination. Less than 10 percent receive an in-depth look by an analyst, but these critiques are essential for the following reasons:

a. To make the organization cognizant of planned and completed work by other government agencies, by the academe and by private industry, and,

b. To prevent many wasted manhours that may be expanded on "reinventing the wheel."

It is a somewhat formidable task to determine the specific research projects to be worked on. The requirements for these projects are updated annually and many more projects are ambitiously planned than can ever be gotten around to. Needs for additional projects surface during the year, and there is the ever present pressure of rapid response tasks that have a way of demanding that previously established priorities change. Manhours expended on these efforts are always on a spasmodic basis of "lesser priority" to the priority tasks, usually being crammed in between rapid response suspense dates.

Most of our documents published are registered in offical channels in the Defense Technical Information Center (DTIC) as well as in the Defense Logistics Studies Information Exchange (DLSIE) for possible use by other government agencies as well as by private industry. Our direct distribution of these completed documents include the cost analysis organizations of other MACOMs, those counterpart elements in the higher command levels and some DOD schools; many requests for our documents are received over a year through both formal and informal channels.

Our research project development progresses through defined phases. In Phase I, the objective(s) of the projects recommended are determined and then selected, rejected, or defered; in Phase II a criteria of key characteristics reflecting the various properties of each selected project(s) are developed; in Phase III initial effort begins towards the new project; and, Phase IV, the project is developed to its completion, it is published and the possible expansion of its concepts are considered for other areas and uses.

Some of these documentations of analyses and computer models are being put to effective use beyond that of the initial requirements/intent of tasking - as case studies in training classes of DOD schools. For over three years, the Army Logistics Management Center (USALMC) has been using the "UTTAS Program" (still called UTTAS and not Black Hawk) as a case study workshop in their Cost Analysis for Decision Making (CADM) course. This material was initially developed over the years, as a sequential part of the DOD acquisition process. Our direct assistance was asked for and provided in structuring of this case study and then again for the subsequent data requirements to make the case study realistic. This workshop is designed to demonstrate, by examples, the qualitative and quantitative estimating techniques used in cost analysis. The students, soon-to-be cost analysts, gain experience in the actual performance of a cost study from the initial study directive that starts the analysis of a major program to the final briefing, becoming acquainted with the many problems and difficulties encountered in an actual study. Results gained from this "hands-on" workshop experience is the improvement of the students' cost analysis vocabulary and their working knowledge of cost estimating relationships, learning curves, uncertainty analysis, work breakdown structure, cost categories, cost models, and parametric estimating. This workshop is a combination of both real and academic experiences designed to expose the students to typical problems faced by cost analysts working in a major subordinate command cost analysis activity, as well as those analysts assigned in a project management office.

Approximately two years ago, in cooperation with the Advanced Scout Helicopter Project Management Office, we responded to the Defense Systems Management College (DSMC) requirement for a computer model for their desired application/adoption in "live" classroom use in their decision analysis exercises. This model, the Cost Benefit Ratio Analysis (CBRA), is self-contained, a general purpose, inter-active program requiring little computer skill of the user. This CBRA technique provides a simple method of rolling up the cost and benefit estimates assigned to the various elements at each level of system structure. Another user, the Black Hawk PMO, has been in need of a quick and accurate data processing of the Production Rate Adjustment Factor (PRAF) model, an outgrowth of CBRA; the first phase of this model is providing that office with a quick "time-phased" investment cost estimate by incorporating the "learning curve" lot size technique with PRAF to calculate "adjusted average lot costs by year." It is significant that the DSMC and these two PMOs have determined that CBRA and its by-product is currently an effective tool in responding to their special requirements.

More recently the DSMC has requested information regarding our parametric life cycle (LCC) model for Army helicopters. The school expressed a need for a production cost planning model for use in supporting the school's systems acquisition management case studies that are now under development. This computer model, originally developed and used in many army aviation programs, provides a rapid response capability for estimating the life cycle cost of hypothetical rotary wing aircraft systems. It was developed for using parametric estimating techniques where possible with the industrial engineering, or an experienced judgement approach being used in lieu of parametric equations for those segments of cost for which reliable historical data is not available. Flexibility is built into the model, allowing the user to modify or even completely substitute for the parametric equation. The main theme behind the creation and use of this model was to provide speed of response and reasonable accuracy within the inherent

limitations of parametric estimating. It provided ready answers to a myriad of "what-ifs" generated over the past years.

To summarize: As a follow-up to specific analytical taskings, we prepare summarization type documents of our expertise in adjusting to the increasing rate of technological and cost changes in military hardware reflected in our completed work. These "real-world" projects become a part of our data base and also serve to expand and cross-fertilize the expertise of analytical skills assigned to the aviation programs. Some of this documentation of experience is further being put to academic use by DOD schools. These documentations, and others, are routinely registered in offical channels in the Defense Documentation Center (DDC) and in the Defense Logistics Studies Information Exchange (DLSIE) for their use by other government agencies as well as by private industry. These publications must meet the strongest of criteria for accuracy, realism and substantiation in order for our efforts to be professionally recognized by experts in government, industry and the academe.

AD P001228

DATA BASE FOR AIRCRAFT OPERATING AND SUPPORT COSTS

Lowell R. E. Weit

As early as the 1960s, the Office of the Secretary of Defense (OSD) identified a requirement for managing and collecting Operating and Support (O/S) costs for major weapon systems. O/S costs have become the most significant part of Life Cycle Cost (LCC) as the complexity of weapon systems has increased. For many weapon systems the O/S cost exceeds 60% of the total LCC. The collection, organization, and publication of O/S cost data is one of the major problems of the cost analysis community. A plethora of O/S cost data is currently collected by individual organizations for the development or expansion of their internal data bases, but these data are normally unavailable or unknown to the remainder of the user community. This results in duplication of effort, unawareness of specific cost data, and many additional hours of research in locating and evaluating cost data.

In 1963 OSD initiated efforts to identify O/S costs by weapon system. There was limited success for this initiative and, in July of 1974, OSD reaffirmed its postion and requested the services report on their efforts and plans to meet this requirement. In addition, OSD identified constraints that would establish some consistency to the collection of O/S cost data for all services. These constraints stated that only existing data systems would be used (no new data collection systems would be developed), that costs would be collected at the total system level, that costs would be displayed in accordance with the Cost Analysis Improvement Group (CAIG) O/S cost format, and that reports would be produced on a Fiscal Year (FY) basis. In November of 1974, the Chief of Naval Operations (CNO) issued a study directive to develop an O/S cost data base by weapon system. In 1975, the Visibility and Management of Operating and Support Costs (VAMOSC)-AIR reporting system was completed and implemented for Navy and Marine Corps aircraft weapon systems. The first VAMOSC-AIR report was published in FY76 on FY75 cost data. Data were provided on approximately 35 Type Model (TM) aircraft.

The VAMOSC-AIR report is a cost display system divided into two major system efforts, the Total Support System (TSS) report and the Maintenance Subsystem (MS) report. The TSS report is for data at the total weapon system level by Type/Model/Series (T/M/S). The MS report is for data at the maintenance level by Work Unit Code (WUC) within each T/M/S. The MS and TSS reports are developed independently, use different data sources, and do not track or combine to give total O/S costs. The criterion for the

collection of O/S cost data are that the data be collected by T/M/S for aircraft with 100 or more flight hours during the designated FY. This accounts for over 95% of the total flight hours accumulated by Navy and Marine Corps aircraft.

The TSS report is divided into six major categories consisting of organizational maintenance support costs, intermediate maintenance support costs, depot support costs, training support costs, recurring investment costs and other costs. In addition to cost data, non-cost data are provided or quantities of aircraft and flying hours for each TMS aircraft. The above data are also displayed according to major claimant, i.e., LANTFLT, PACFLT, Marines, Reserves, NAVEUR, and others.

Data are collected for the TSS report using a "top down" approach to include the broadest spectrum of O/S cost data currently attributable to aircraft systems. Cost data are requested by operating activity using Unit Identification Code (UIC) and T/M/S, or as a minimum, the TM aircraft. If the cost data are not identifiable to an operating activity, the costs are allocated according to flying hours of operation or number of operating aircraft by TMS for each major claimant. Data are collected from 12 data sources (see attached Figure 1) and are processed through a sequence of 17 batch process programs. The program output identifies and allocates the costs to 67 elements for each TMS by major claimant (see Figures 2 through 6).

The MS report was developed to comply with Objective 3, Action 12, of the Department of Defense (DOD) FY75 Management By Objectives (MBO). This objective required the presentation of detailed maintenance cost data by T/M/S at the subsystem level (two-digit WUC), component or Weapons Replaceable Assembly (WRA) level (five-digit WUC), and Shop Replaceable Assembly (SRA) level (seven-digit WUC).

The MS report is a "bottom-up" cost display system that consolidates maintenance hours and cost by WUC within each T/M/S. Actual cost data are used as input to the MS report; however, if actual data are not available, the costs are estimated or allocated by other methods, depending on the activity reporting the data. The MS report provides data on approximately 120 TMS aircraft systems. Aircraft are selected based on the total number of flight hours accumulated during the designated FY.

Data are collected from three major sources: the Maintenance and Material Management (3M) system, Master Component Rework Control (MCRC) system, and Aviation Support Office (ASO). The data required to support the MS report include: maintenance actions records, material reporting records, repairable item data records, support action form records, aircraft flight data records, and summary data records.

The 3M data Fleet Originated Jobs (FOJ) files provide over 90% of the input data, including maintenance hours, maintenance actions, and material used at the organizational and intermediate levels of maintenance. The MCRC system provides data on depot standard costs to repair/rework a component. These data include standard direct labor, indirect labor, and material costs at the National Item Identification Number (NIIN) level. The ASO provides commercial contractor data extracted manually from the ASO contract files and recorded by the NIIN.

Production of the MS report is completed in four steps. Step one is the system segment where the cross reference and cost files are built to apply costs by the NIIN to maintenance actions records where costing is necessary. Step two is the system segment in which data are extracted from the FOJ files to build a summary record by Job Control Number (JCN) for subsequent processing. Step three of the system summarizes the data in the JCN records and computes costs where applicable. Data are stored at the Type Equipment Code (TEC)/WUC level in this segment. Step four of the system is where data are selected for the various reports, calculated, and formatted as required.

The MS report consists of eight categories (subreports) which provide cost data and non-cost data identified to the three levels of maintenance-organizational, intermediate, and depot. These eight categories are:

1. TOTAL COMPONENT MAINTENANCE COST REPORT FOR ALL NAVY summarizes labor and material costs for organizational, intermediate and depot level maintenance actions. Labor costs are reported for direct labor hours, support hours and Technical Directive Compliance (TDC) labor hours. Material costs are reported for consumable material to identify the cost of attrition and surveyed (condemned) items (see Figure 7).

2. TOTAL COMPONENT MAINTENANCE COST REPORT FOR ALL NAVY (UNSCHEDULED) summarizes labor and material costs for organizational (level 1), intermediate (level 2), and depot (level 3) maintenance actions. Material costs are for the consumable materials used in unscheduled repair or rework of components and to identify the cost of surveyed items. Labor costs are for the direct labor applied for the unscheduled maintenance actions at each maintenance level (see Figure 8).

3. TOTAL COMPONENT MAINTENANCE COST REPORT FOR ALL NAVY (SCHEDULED) summarizes labor and material costs for organizational (level 1), intermediate (level 2), and depot (level 3) maintenance actions. Material costs are for the consumable materials used in scheduled repair or rework of components. Labor costs are for the direct labor applied and indirect

labor for the scheduled maintenance actions at each maintenance level (see Figure 9).

4. & 5. TOTAL MAINTENANCE ACTION MATRIX REPORT for both unscheduled and scheduled maintenance provides data on the number of maintenance actions, action taken codes, and level 3 repairs and surveys. The data reports are on organizational, intermediate, and depot activities. The code assignments are made as part of the 3M system with specific direction from OPNAVINST 4790.2B (see Figures 10 and 11).

6. MAN-HOUR MATRIX REPORT provides man-hour utilization data by WUC. The report represents data on unscheduled, scheduled, support, and TDC labor. Within each of these labor categories, data are reported for organizational, intermediate, and depot levels of maintenance (see Figure 12).

7. TOTAL COST OF CONSUMABLES REPORT provides a count of the number of repairables and consumable issues and the cost of consumables for organizational and intermediate levels of maintenance (see Figure 13).

8. AVERAGE COST PER REPAIR MATRIX REPORT identifies the average cost of materials for organizational, intermediate, and depot repairs and the average cost of depot (level 3) labor (see Figure 14).

The VAMOSC-AIR MS and TSS program has some limitations in regard to the scope, timeliness, validity of data, and usage of the data. The major limitations are:

1. VAMOSC-AIR is not a real time system. It is an annual processing system with data interfaces with other data sources.

2. VAMOSC-AIR is processed on a FY basis with input data available about 180 days after the end of the FY.

3. VAMOSC-AIR is not an on-line system. The user must use the standard reports produced on an annual basis.

4. VAMOSC-AIR data are obtained from existing Navy data systems and, therefore, the data are constrained by the accuracy and timeliness of various feeder systems.

5. VAMOSC-AIR MS depot data are derived by using BCM-9 data from intermediate level maintenance as the source of projected depot maintenance actions. Standard Depot Level Maintenance (SDLM) actions are not included in the depot cost.

6. Some of the cost data are calculated using average rates, budget data, standards, and statistical techniques when actual data are not available or data gaps exist.

The VAMOSC-AIR program provides a significant amount of data to the cost analysis community. It provides a centralized data base for O/S costs on Navy and Marine Corps aircraft systems. The data are at the total system level according to the CAIG format and at the maintenance level down to the seventh WUC. Also, there are MS and TSS reports available for the past seven years which can be used to identify maintenance trends for specific T/M/S aircraft.

The VAMOSC report is currently being used by DOD activities and contractors for Design to Cost, Life Cycle Cost, Operations Analysis, establishment of baseline costs, proposal evaluations, programming and budget submissions, trend analysis, O/S cost models, and other related cost functions.

The VAMOSC reports not only provide maintenance cost by T/M/S, but also identify cost drivers and cost factors as an aid to projecting outyear maintenance costs. These factors are derived through the use of internal algorithms from input data extracted from the 3M system, MCRC, and commercial component repair costs reports. This type of information expands the VAMOSC-AIR program beyond just a cost display system and makes it an analytical tool for the calculation of future aircraft system maintenance cost and resource requirements projections. The cost drivers and factors provided are:

MFHBF	Mean Flight Hour Between Failures
MFHBMA	Mean Flight Hours Between Maintenance Actions
MA/FH	Maintenance Actions per Flight Hour
MH/FH	Maintenance Hours per Flight Hour
MC/FH	Maintenance Cost per Flight Hours (T/M/S)
MC/AC	Maintenance Cost per Aircraft (T/M/S)

The VAMOSC-AIR program meets the OSD requirement to identify O/S costs by aircraft weapon system. The program is still in its early stages and will require extensive resources, manpower, and funds to enhance the program in order to achieve program credibility. Also, the program needs extensive marketing to identify itself to all potential users through the use of workshops, briefings, and brochures.

The TSS and MS reports are available to DOD activities and DOD contractors at no cost, except for special studies. The TSS report is a two-volume report on all T/M/S aircraft. The MS reports are provided at the two-digit, five-digit, and seven-digit WUC by TM. Included within each TM report are all TMS aircraft.

TSS DATA SOURCES

- CNO FLYING HOUR PROGRAM (OP-51)-
  - MAINTENANCE SUPPLIES
  - PERSONNEL SUPPORT SUPPLIES
  - PETROLEUM, OIL, AND LUBRICANT (POL) COSTS

- NAVY COST INFORMATION SYSTEM/ OPERATING SUBSYSTEM (NCIS/OPS)
  - PERSONNEL COSTS
  - TEMPORARY ADDITIONAL DUTY (TAD) COSTS

- US MARINE CORPS HEADQUARTERS
  - PERSONNEL COSTS
  - TAD COSTS

- SHIPS PARTS CONTROL CENTER/CONVENTIONAL AMMUNITION INTEGRATED MANAGEMENT SYSTEM (SPCC/ CAIMS)
  - TRAINING EXPENDABLE STORES

- BUDGET DATA FROM THE NAVAL AVIATION LOGISTICS CENTER
  - AIRCRAFT REWORK
  - ENGINE REWORK
  - COMPONENT REWORK
  - MISC. REWORK

- FLEET AVIATION SPECIALIZED OPERATIONAL TRAINING GROUPS
  - OPERATIONAL TRAINING COSTS (FASOTRAGRU-LANT/PAC)

- CHIEF OF NAVAL EDUCATION AND TRAINING
  - MAINTENANCE TRAINING COSTS

- VAMOSC-AIR MAINTENANCE SUBYSTEM
  - REPLACEMENT REPAIRABLES

- NAVAIR-01A6
  - MODIFICATION COSTS

- NAVAL AVIATION ENGINEERING SERVICE UNIT - ENGINEERING TECHINCAL SERVICES

- NAVAL AVIATION TECHNICAL SERVICES FACILITY - PUBLICATION COSTS

- NAVAL AVIATION LOGISTICS CENTER
  - AVIATION COSTS
  - SURVEY COSTS
  - DEPOT COSTS

Figure 1

NALCOMIS-O&S/VAMOSC-AIR

NAVY AND MARINE CORPS AIRCRAFT COST REPORT BY T/M/S

VAMOSC-AIR TSS FY 1978 ($ IN THOUSANDS; DATA AS LISTED) T/M/S: UH-1E PAGE 1

	PACFLT	LANTFLT	NET	MARINE	RESERVE	NAVAIR	OPNAV	NAVEUR	MISC	TOTAL
AIRCRAFT NUMBER										
REGULAR	.0	.0	28.0	.0	20.0	2.0	.0	.0	.0	50
FLEET READINESS SQUADRON	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
*** TOTAL AIRCRAFT NUMBER	.0	.0	28.0	.0	20.0	2.0	.0	.0	.0	50
FLYING HOURS										
REGULAR	.0	402.0	9,911.0	.0	3,861.0	267.0	.0	.0	.0	14,441
FLEET READINESS SQUADRON	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
*** TOTAL FLYING HOURS	.0	402.0	9,911.0	.0	3,861.0	267.0	.0	.0	.0	14,441

	PACFLT	LANTFLT	NET	MARINE	RESERVE	NAVAIR	OPNAV	NAVEUR	MISC	TOTAL
ORGANIZATIONAL										
MILITARY PERSONNEL COST	.0	.0	.0	.0	568.0	.0	.0	.0	.0	568
CIVILIAN PERSONNEL COST	.0	.0	.0	N/A	.0	.0	.0	.0	.0	0
CONTRACT PERSONNEL COST	.0	.0	.0	N/A	.7	.0	.0	.0	.0	0
** SUBTOTAL PERSONNEL	.0	.0	.0	.0	568.7	.0	.0	.0	.0	568
TEMPORARY ADDITIONAL DUTY	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
TRAINING EXPENDABLE STORES	.0	18.6	.0	.0	.0	1.1	.0	.0	.0	19
MAINTENANCE SUPPLIES	.0	.0	425.1	.0	243.5	.0	.0	.0	.0	668
PERSONNEL SUPPORT SUPPLIES	.0	.0	59.4	.0	42.3	4.3	.0	.0	.0	106
POL COSTS	.0	16.8	280.9	.0	134.5	17.6	.0	.0	.0	450
*** ORGANIZATIONAL SUBTOTAL	.0	35.4	765.6	.0	989.2	23.1	.0	.0	.0	1,813

Figure 2

NALCOMIS-O&S/VAMOSC-AIR

NAVY AND MARINE CORPS AIRCRAFT COST REPORT BY T/M/S

VAMOSC-AIR TSS FY 1978 ($ IN THOUSANDS: DATA AS LISTED) T/M/S: UH-1E

	PACFLT	LANTFLT	NET	MARINE	RESERVE	NAVAIR	OPNAV	NAVEUR	MISC	TOTAL
INTERMEDIATE										
MILITARY PERSONNEL COST	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
CIVILIAN PERSONNEL COST	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
CONTRACT PERSONNEL COST	.0	.0	46.7	.0	.0	.0	.0	.0	.0	46
** SUBTOTAL PERSONNEL	.0	.0	46.7	.0	.0	.0	.0	.0	.0	46
MAINTENANCE SUPPLIES	.0	6.7	201.2	.0	95.3	62.7	.0	.0	.0	366
*** INTERMEDIATE SUBTOTAL	.0	6.7	248.0	.0	95.3	62.7	.0	.0	.0	412

	PACFLT	LANTFLT	NET	MARINE	RESERVE	NAVAIR	OPNAV	NAVEUR	MISC	TOTAL
DEPOT SUPPORT										
AIRCRAFT REWORK INTRA-DOD	.0	70.8	1,747.7	.0	680.8	108.8	.0	.0	.0	2,608
AIRCRAFT REWORK COMMERCIAL	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
** SUBTOTAL A/C REWORK	.0	70.8	1,747.7	.0	680.8	108.8	.0	.0	.0	2,608
ENGINE REWORK INTRA-DOD	.0	6.1	151.8	.0	59.1	5.0	.0	.0	.0	222
ENGINE REWORK COMMERCIAL	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
** SUBTOTAL ENG REWORK	.0	6.1	151.8	.0	59.1	5.0	.0	.0	.0	222

Figure 3

NALCOMIS-O&S/VAMOSC-AIR

NAVY AND MARINE CORPS AIRCRAFT COST REPORT BY T/M/S

VAMOSC-AIR T5S FY 1978 ($ IN THOUSANDS: DATA AS LISTED) T/M/S: UH-1E PAGE 3

	PACFLT	LANTFLT	NET	MARINE	RESERVE	NAVAIR	OPNAV	NAVEUR	MISC	TOTAL
COMPONENT REWORK INTRA-DOD	.0	16.7	412.6	.0	160.7	4.3	.0	.0	.0	594
COMPONENT REWORK COMMERCIAL	.0	.1	2.6	.0	1.0	.0	.0	.0	0	3
** SUBTOTAL COMP REWORK	.0	16.8	415.2	.0	161.7	4.3	.0	.0	.0	598
OTHER REWORK MISC DEPOT	.0	11.4	281.8	.0	109.7	25.0	.0	.0	.0	428
OTHER REWORK ENG. SUPPORT	.0	3.2	81.0	.0	31.5	7.2	.0	.0	.0	123
** SUBTOTAL OTH REWORK	.0	14.7	362.8	.0	141.3	32.2	.0	.0	.0	551
*** SUBTOTAL DEPOT SUPPORT	.0	108.6	2,577.8	.0	1,043.1	150.5	.0	.0	.0	3,980

	PACFLT	LANTFLT	NET	MARINE	RESERVE	NAVAIR	OPNAV	NAVEUR	MISC	TOTAL
TRAINING SUPPORT										
FRS MILITARY PERSONNEL COST	.0	.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
FRS CIVILIAN PERSONNEL COST	.0	.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
FRS CONTRACT PERSONNEL COST	.0	.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
** SUBTOTAL FRS PERSONNEL	.0	.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
FRS TEMP. ADD. DUTY	.0	.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
FRS TRAIN. EXPEND. STORES	.0	.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
FRS MAINT. SUP.	.0	.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
FRS PERS. SUPP. SUP.	.0	.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
FRS POL	.0	.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
** SUBTOTAL FRS	.0	.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0

Figure 4

NALCOMIS-O&S/VAMOSC-AIR

NAVY AND MARINE CORPS AIRCRAFT COST REPORT BY T/M/S

VAMOSC-AIR TSS FY 1978 ($ IN THOUSANDS; DATA AS LISTED) T/M/S: UH-1E

	PACFLT	LANTFLT	NET	MARINE	RESERVE	NAVAIR	OPNAV	NAVEUR	MISC	TOTAL
OPERATIONAL TRAINING	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
MAINTENANCE TRAINING	.0	.0	66.5	.0	47.5	2.3	.0	.0	.0	116
** SUBTOTAL O/M TRAIN.	.0	.0	66.5	.0	47.5	2.3	.0	.0	.0	116
*** SUBTOTAL TRAIN. SUPP.	.0	.0	66.5	.0	47.5	2.3	.0	.0	.0	116

	PACFLT	LANTFLT	NET	MARINE	RESERVE	NAVAIR	OPNAV	NAVEUR	MISC	TOTAL
RECURRING INVESTMENT										
REPLACEMENT REPAIRABLES	.0	24.3	601.0	.0	234.1	6.3	.0	.0	.0	865
MODIFICATIONS	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
*** SUBTOTAL RECUR INVEST.	.0	24.3	601.0	.0	234.1	6.3	.0	.0	.0	865

	PACFLT	LANTFLT	NET	MARINE	RESERVE	NAVAIR	OPNAV	NAVEUR	MISC	TOTAL
OTHER FUNCTIONS										
NETS	.0	.0	16.1	.0	11.5	1.1	.0	.0	.0	28
CETS	.0	.0	63.7	.0	45.5	4.5	.0	.0	.0	113
PUBLICATIONS	.0	.0	4.6	.0	3.3	.3	.0	.0	.0	8
*** SUBTOTAL OTHER FUNCTIONS	.0	.0	84.5	.0	60.3	6.0	.0	.0	.0	150

Figure 5

NALCOMIS-OOS/VAMOSC-AIR

NAVY AND MARINE CORPS AIRCRAFT COST REPORT BY T/M/S

VAMOSC-AIR TSS FY 1978 ($ IN THOUSANDS; DATA AS LISTED) T/M/S: UH-1E PAGE 5

	PACFLT	LANTFLT	NET	MARINE	RESERVE	NAVAIR	OPNAV	NAVEUR	MISC	TOTAL
SUMMARY OF T/M/S										
ORGANIZATIONAL	.0	35.4	765.6	.0	989.2	23.1	.0	.0	.0	1,813
INTERMEDIATE	.0	6.7	248.0	.0	95.3	62.7	.0	.0	.0	412
DEPOT SUPPORT	.0	108.6	2,677.8	.0	1,043.1	150.5	.0	.0	.0	3,980
TRAINING SUPPORT	.0	.0	66.5	.0	47.5	2.3	.0	.0	.0	116
RECURRING INVESTMENT	.0	24.3	601.0	.0	234.1	6.3	.0	.0	0	865
OTHER FUNCTIONS	.0	.0	84.5	.0	60.3	6.0	.0	.0	0	150
*** OVERALL TOTALS	.0	175.2	4,443.6	.0	2,469.8	251.2	.0	.0	.0	7,339

Figure 6

TOTAL COMPONENT MAINTENANCE COST

ALL-NAVY SQUADRONS

(SCHEDULED AND UNSCHEDULED)

AIRCRAFT = F-14A TYPE EQUIPMENT = AFHA OCT. 79 - SEPT. 80

TOTAL COMPONENT MAINTENANCE COSTS (IN THOUSANDS OF $)

ORG.LEVEL LABOR RATE = 17.89 PER HOUR
INT.LEVEL LABOR RATE = 17.89 PER HOUR

ALL-NAVY SQUADRONS

WORK UNIT CODE	ORGANIZATION MAINTENANCE LABOR SCH	ORGANIZATION MAINTENANCE LABOR UNSCH	ORGANIZATION MAINTENANCE CONSUM SCH	ORGANIZATION MAINTENANCE CONSUM UNSCH	ORGANIZATION SUPPT LABOR	ORGANIZATION TDC LABOR	INTERMEDIATE MAINTENANCE LABOR SCH	INTERMEDIATE MAINTENANCE LABOR UNSCH	INTERMEDIATE MAINTENANCE CONSUM SCH	INTERMEDIATE MAINTENANCE CONSUM UNSCH	INTERMEDIATE SUPPT LABOR	INTERMEDIATE TDC LABOR	INTERMEDIATE ATTR	DEPOT COMPONENT REPAIR D-LAB	DEPOT COMPONENT REPAIR I-LAB	DEPOT COMPONENT REPAIR MAT	DEPOT COMMERC LABOR	DEPOT COMMERC MAT	DEPOT SUBV	TDC LABOR	TDC TOTAL COST
-9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
03	6555	64	31	7	1532	2	782	16	30	39	20	0	0	1	1	5	0	0	3	0	9068
04	141	2	0	0	32	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	176
11	1006	1962	29	641	1130	116	17	274	0	473	12	153	45	82	58	252	0	1	171	0	7222
12	35	369	21	229	119	23	0	32	0	42	2	0	0	4	4	10	1	1	2	0	909
13	106	1272	35	606	410	98	45	662	3	295	40	1	19	299	219	906	0	1	779	0	5756
14	213	2241	0	479	737	42	12	416	3	193	10	9	0	81	60	251	19	44	130	0	4931
TOTAL	9864	20714	284	9579	8544	555	1608	12011	241	5410	702	276	190	2029	1483	5005	104	310	2208	0	85205

PRE-EX MAT 7330
UNALLOC ORG SUPPT LAB 1161
ORG TDC MAT 0
INT TDC MAT 0
DEP TDC MAT 0

TOTAL OPERATING AIRCRAFT 320

TOTAL FLIGHT HOURS 866V4.9

GRAND TOTAL FOR 91210

Figure 7

TOTAL COMPONENT MAINTENANCE COSTS UNSCHEDULED

AIRCRAFT = F-14A TYPE EQUIPMENT = AEWA OCT. 79 - SEPT. 80

TOTAL COMPONENT MAINTENANCE COSTS ($K)

UNSCHEDULED

ALL-NAVY SQUADRONS

ORGANIZATION LABOR RATE = $17.09 PER HOUR

INTERMEDIATE LABOR RATE = $17.09 PER HOUR

WORK UNIT CODE	MATERIAL LEVEL-1 REPAIR	LEVEL-2 REPAIR	AIMD REPAIR	LEVEL-3 REPAIR NAVF	LEVEL-3 REPAIR CONN.	SURVEY	TOTAL MATERIAL	LABOR LEVEL-1 MAINT*	LABOR LEVEL-2 MAINT*	LABOR LEVEL-3 DIRECT NAVF	LABOR LEVEL-3 DIRECT CONN.	TOTAL LABOR	TOTAL COST	UNSCHED. COST/ FAILURE ($)	MEHRF	MEHRMA
	0	0	0	0	0	0	0	0	0	0	0	0	0	0.	0.0	86695.0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0.	0.0	86695.0
01	7	32	0	2	0	2	50	64	16	1	0	81	131	3037.	2409.2	277.9
04	0	0	0	0	0	0	0	2	0	0	0	2	2	500.	21673.8	6660.8
11	641	473	30	239	1	345	1537	1962	274	70	0	2306	3843	1025.	41.1	11.9
12	229	42	0	16	1	2	290	369	39	4	1	413	703	250.	31.8	13.7
13	606	295	15	820	1	717	2454	1272	662	294	0	2228	4702	602.	10.9	10.9
14	490	143	0	253	44	120	1050	2241	416	80	19	2756	3814	690.	15.7	9.3
TOTAL ALL WUCS ($K)	9579	5119	184	5495	310	1790	22767	20714	12011	1928	184	34837	57604	6213.	9.9	60.9
PERCENT PER COST CATEGORY	16.6	9.4	0.3	9.5	0.5	3.1	39.5	36.0	20.9	3.3	0.3	60.5	100.0			

PERCENT OF COST CATEGORY

														TOTAL COST($K)	COST($)/FAIL
AF	20.7	10.4	29.3	25.6	15.2	57.3	24.2	28.5	11.7	23.0	10.9	22.4	23.1	13300.	1500.
FF	7.4	16.1	0.5	27.2	0.4	10.5	15.6	14.5	12.2	27.2	27.7	16.9	16.3	9417.	2643.
AV	71.9	65.6	70.1	45.2	76.5	24.2	60.2	57.0	69.1	49.8	61.4	60.8	60.5	34878.	9819.

MAINT. LEVEL COST SUMMARY ($K)

	MATERIAL	LABOR	TOTAL
SQUADRON(1)	9579.	20714.	30293.
INTERMEDIATE(2)	5595.	12011.	17605.
DEPOT(3)	1594.	2112.	9706.

FLIGHT HOUR SUMMARY

COMBAT	2.	COMBAT	1.
NON-COMBAT	86693.	NON-COMBAT	53193.
TOTAL FH	86695.	TOTAL FLIGHTS	53194.

COST($) PER FH		LEVEL-1	LEVEL-2
	MATERIAL ONLY	263. MA/FH	2.2	0.9
	MATERIAL + DEPOT LABOR	287. MM/FH	1.9	1.0
	MATERIAL + ALL LABOR	664.		

COST($) OPERATING AIRCRAFT 180613.

Figure 8

TOTAL COMPONENT MAINTENANCE COSTS SCHEDULE

AIRCRAFT = F-14A TYPE EQUIPMT = AFHA OCT. 79 - SEPT. 80

TOTAL COMPONENT MAINTENANCE COSTS (1K)

SCHEDULED

ALL-NAVY SQUADRONS

ORGANIZATION LABOR RATE = $17.82 PER HOUR
INTERMEDIATE LABOR RATE = $17.89 PER HOUR

WORK UNIT CODE	MATERIAL LEVEL-1 REPAIR	LEVEL-2 REPAIR	ATTNI REPAIR	NAVF REPAIR	COMM. REPAIR	SURVEY	TOTAL MATERIAL	LABOR LEVEL-3 MAINT	SUPPORT	TUC	LABOR LEVEL-2 MAINT	SUPPORT	TUC	LABOR LEVEL-1 DIRECT	NAVF	COMM. INDIRECT	TUC	TOTAL MAT'L COST	TOTAL LABOR COST
-9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
03	31	30	0	3	0	1	69	6555	1532	2	762	20	0	1	0	0	0	8072	8731
04	0	0	0	0	0	0	0	191	32	0	1	0	0	0	0	0	0	223	223
11	29	0	7	14	0	26	76	1806	1130	116	17	12	153	5	0	3	0	3242	3318
12	21	0	0	3	0	0	24	39	119	23	0	2	0	0	0	0	0	119	223
13	35	3	4	17	0	31	90	106	410	58	43	40	1	6	0	4	0	670	760
19	0	3	0	5	0	19	26	213	137	42	12	18	0	1	0	0	0	1932	1958
TOTAL ALL WUCS (1K)	284	241	16	NAVF 310	COMM. 0	419	1260	9004	8544	959	1600	702	216	NAVF 95	0	COMM. 60	0	21012	23080

ADDITIONAL SCHED. COSTS FOR AIRCRAFT (1K)

EXPENDABLE CONSUMABLE COST(LEVEL 1)	7330
EXPENDABLE CONSUMABLE COST(LEVEL 2)	0
TUC MATERIAL COST	0
UNALLOCATED SUPPORT LABOR	2626

							ADJUSTED TOTAL													
							8598											24438	33036	
FRONT	0.9	0.7	0.0	0.9	0.0	1.3	3.0	27.9	29.9	1.7	4.9	2.4	0.8	0.3	0.0	0.2	0.0	66.4	100.0	
PER COST CATEGORY							26.0											74.0		
PERCENT OF COST CATEGORY BY SUBSYSTEM																				
AF	43.7	15.4	18.5	13.5	8.0	16.8	22.2	75.1	90.3	93.4	92.1	11.0	59.1	13.1	0.0	19.3	0.0	67.1	65.2	
PP	12.0	0.3	0.0	18.7	0.0	83.3	51.0	1.2	11.1	7.0	18.5	20.3	0.8	61.1	0.0	83.3	0.0	7.9	10.3	
AV	44.4	76.3	21.4	7.7	0.0	0.3	26.7	3.1	42.8	49.9	29.4	87.9	31.2	5.3	0.0	4.4	0.0	24.9	24.5	

MAINT. LEVEL COST SUMMARY (1K)

	MATERIAL	LABOR	TOTAL
SQUADRON(1)	7619.	12003.	20071.
INTERMEDIATE(2)	255.	2711.	2966.
DEPOT(3)	747.	163.	822.

FLIGHT HOUR SUMMARY

COMBAT	2.	COMBAT	1.	
NON-COMBAT	8869.	NON-COMBAT	53153.	
TOTAL FH	8869.	TOTAL FLIGHTS	53154.	

COSTS($) PER FH			LEVEL-1	LEVEL-2
	MATERIAL ONLY	27.	MMCPFH	0.3 0.0
	MATERIAL + DEPOT LABOR	121.	MMCPFH	6.4 1.0
	MATERIAL + ALL LABOR	271.		

TOTAL MAINTENANCE ACTION MATRIX UNSCHEDULED

AIRCRAFT = F-14A TYPE EQUIPMENT = AIMA OCT. FY - SEPT. 80

TOTAL MAINTENANCE ACTION MATRIX

ALL-NAVY SQUADRONS

UNSCHEDULED MAINTENANCE ONLY

WORK UNIT CODE	LEVEL-1 M-A	LEVEL-1 M/C	LEVEL-1 M	LEVEL-1 T	LEVEL-1 FAILURES	LEVEL-2 M-A	LEVEL-2 M/C	LEVEL-2 A	LEVEL-2 Z	LEVEL-2 UCM Y FAILURES	LEVEL-3 UCM-U CORR REPAIRS	LEVEL-3 MAINT REPAIRS	LEVEL-3 MAINT SURVEYS	TOTAL M-A	TOTAL FAIL
02	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
03	353	10	5	0	7	150	27	132	14	1	29	0	0	312	36
04	19	2	0	1	2	4	1	2	0	0	2	1	0	13	4
11	21094	15092	1331	653	12212	1359	432	676	15	137	995	523	2	107	16	22209	12119
12	6246	3523	500	257	2764	344	109	92	14	25	212	145	5	71	1	6313	2727
13	13377	4214	6257	1505	6766	7759	3876	4076	209	309	3312	2946	2	714	115	14820	7749
14	8714	3000	2133	906	5030	2443	1047	475	13	48	2006	1076	37	309	27	9305	5529
TOTAL	170321	70946	50043	29769	107754	61792	42057	21225	1206	1439	57619	22650	834	6132	391	211257	124212
PERCENT BY SUBSYSTEM															
AF	.2	.0	.0	.0	.0	.2	.1	.6	1.1	.1	.1	.0	.0	.0	.0	.2	.0
PP	32.9	46.4	24.2	19.1	32.9	22.5	10.6	34.9	20.9	45.9	10.9	34.7	23.4	37.2	66.9	32.9	29.7
AV	66.9	53.6	75.8	80.9	67.1	77.3	81.4	64.4	78.0	54.0	81.0	65.3	76.6	62.7	33.1	67.1	70.3

Figure 10

TOTAL MAINTENANCE ACTION MATRIX SCHEDULED

AIRCRAFT = F-14A TYPE EQUIPMENT = AF-A OCT, 77 - SEPT, 80
TOTAL MAINTENANCE ACTION MATRIX
ALL-NAVY SQUADRONS
SCHEDULED MAINTENANCE ONLY

WORK UNIT CODE	LEVEL-I M-A	D/C	A	I	FAILURES	LEVEL-2 M-A	D/C	A	I	MCH 9 FAILURES	DEPOT-D COMP	LEVEL-3 MAINT REPAIRS	REPAIRS	SURVEYS	TOTAL M-A	FAIL.
00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
03	3297	63	12	0	55	1162	03	397	5	0	02	61	0	3	0	4675	122
04	1540	12	0	0	12	4	0	1	0	0	0	0	0	0	0	1540	3
11	15447	1058	70	5	1493	205	26	270	1	5	47	25	0	0	0	15573	1107
12	2289	179	55	0	192	39	1	4	0	2	44	36	0	21	0	2297	161
13	1238	152	371	21	106	378	106	271	1	11	96	153	0	22	5	1302	291
14	1608	267	47	13	235	167	7	175	0	4	33	28	0	9	3	1803	243
TOTAL	5709	4493	2691	433	4647	7520	1583	4410	35	130	2496	2169	2	462	106	37709	5171
PERCENT BY SUBSYSTEM																	
AF	14.0	1.7	.4	.0	1.4	23.5	5.2	9.0	14.3	.0	2.4	2.4	.0	.6	.9	16.5	1.9
EP	16.1	62.6	27.7	12.9	52.4	20.3	38.2	29.8	42.9	18.1	47.0	17.6	.9	85.1	99.5	61.5	52.6
AV	19.1	35.7	72.9	87.1	46.1	46.2	56.5	70.2	42.9	81.9	50.6	18.1	100.0	14.3	.9	22.1	45.4

Figure 11

MAN HOUR MATRIX

AIRCRAFT = F-14A TYPE EQUIPMENT = AFHA OCT. 79 - SEPT. 80
MAN HOUR MATRIX
ALL NAVY SQUADRONS

WORK UNIT CODE	UNSCHEDULED MAINTENANCE LEVEL-1 TOTAL	UNSCHEDULED MAINTENANCE LEVEL-1 MH/MA	UNSCHEDULED MAINTENANCE LEVEL-2 TOTAL	UNSCHEDULED MAINTENANCE LEVEL-2 MH/MA	UNSCHEDULED MAINTENANCE LEVEL-3 TOTAL	UNSCHEDULED MAINTENANCE LEVEL-3 MH/MA	SCHEDULED MAINTENANCE LEVEL-1 TOTAL	SCHEDULED MAINTENANCE LEVEL-1 MH/MA	SCHEDULED MAINTENANCE LEVEL-2 TOTAL	SCHEDULED MAINTENANCE LEVEL-2 MH/MA	SCHEDULED MAINTENANCE LEVEL-3 TOTAL	SCHEDULED MAINTENANCE LEVEL-3 MH/MA	SUPPORT LEVEL-1 TOTAL	SUPPORT LEVEL-2 TOTAL	TDY LEVEL-1 TOTAL	TDY LEVEL-2 TOTAL	TDY LEVEL-3 TOTAL
-9	1	1.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0	0	0	0
01	2	2.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0	0	0	0
03	3654	10.4	914	6.1	53	26.5	366306	111.1	42573	24.2	62	20.7	85607	1110	88	2	0	0
04	130	6.8	10	2.5	0	0.0	41331	26.7	20	1.0	0	0.0	1901	0	0	0	0	0
11	116671	58.4	16263	12.0	6562	35.1	162072	18.9	1334	8.5	361	45.1	63620	849	6890	8579	0	0
12	21302	3.4	2305	6.9	467	6.6	2227	1.0	42	1.1	22	4.4	6601	94	1153	0	0	0
13	71971	21.3	37741	4.9	24147	33.8	6239	5.9	2667	6.9	450	20.0	23179	2391	3333	38	0	0
14	125629	14.4	23461	7.6	6978	17.9	12355	7.3	996	4.0	165	18.3	41533	1362	2297	101	0	0
TOTAL	173205		880628		160370		590246		92224		8573		401578	45414	33314	15020	0	
AVERAGE MH/MA		20.0		379.0		26.2		200.9		12.3		18.6						
PRIME AE	193.		12.		24.		95.		91.		11.		59.	13.	92.	21.	0.	
AVER. AE		506.3		39.0		28.0		96.4		10.5		17.5						
PRIME PP	97.		19.		27.		1.		10.		79.		11.	20.	7.	10.	0.	
AVER. PP		33.9		20.9		47.5		7.2		12.9		20.4						
PRIME AV	187.		69.		49.		4.		30.		8.		43.	87.	50.	31.	0.	
AVER. AV		249.6		145.6		20.4		3.3		7.6		10.5						

Figure 12

TOTAL COST OF CONSUMABLES "O"&"I" LEVEL ONLY

AIRCRAFT = F-14A TYPE EQUIPMENT = AFHA OCT. 79 - SEPT. 80

TOTAL COST OF CONSUMABLES

ORGANIZATION AND INTERMEDIATE LEVEL ONLY

ALL-NAVY-SQUADRONS

* ADJUSTMENT FACTOR = RATIO OF LEVEL-I REMOVALS TO LEVEL-I REPAIRABLE ISSUES FOR ALL-NAVY SQUADRONS

WORK UNIT CODE	LEVEL-1 NUM.REP.ISSUES	LEVEL-1 NUM.CONS.ISSUES	LEVEL-1 CONS.COST	LEVEL-2 NUM.REP.ISSUES	LEVEL-2 NUM.CONS.ISSUES	LEVEL-2 CONS.COST	ADJUSTMENT FACTOR *
-9	0	0	0.	0	0	0.	0.0
04	0	0	0.	0	0	0.	0.0
03	91	243	38744.	44	19	6991.	0.2
04	1	1	176.	1	1	529.	0.0
11	1125	2722	609166.	20	243	91871.	1.2
12	378	1297	260546.	29	64	43245.	1.9
13	3093	2892	653192.	2986	192	305810.	2.1
14	1269	1065	499920.	529	718	140233.	1.7

WORK UNIT CODE	LEVEL-1 NUM.REP.ISSUES	LEVEL-1 NUM.CONS.ISSUES	LEVEL-1 CONS.COST	LEVEL-2 NUM.REP.ISSUES	LEVEL-2 NUM.CONS.ISSUES	LEVEL-2 CONS.COST	ADJUSTMENT FACTOR *
TOTAL	32004	20419	8218258.	26522	10252	5697192.	
AVERAGE							1.9

Figure 13

AVERAGE COST MATRIX (PER REPAIR)

AIRCRAFT = F-14A TYPE EQUIPMENT = AFWA OCT. 79 - SEPT. 80

AVERAGE COST MATRIX (PER REPAIR)

*BASED ON ALL-NAVY SQUADRONS

WORK UNIT CODE	MATERIAL LEVEL-1 REPAIR (CONS.)	MATERIAL LEVEL-2 REPAIR (CONS.)	MATERIAL LEVEL-2 ATIR*	MATERIAL LEVEL-3 REPAIR HARF	MATERIAL LEVEL-3 REPAIR COMM.	MATERIAL LEVEL-3 SURVEYS	LABOR (LEVEL-3 ONLY) DIRECT HARF	LABOR (LEVEL-3 ONLY) DIRECT COMM.	LABOR (LEVEL-3 ONLY) INDIRECT	DEPOT LABOR RATE
-9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
83	10.67	36.56	0.00	842.25	0.00	0.00	280.82	0.00	206.45	21.39
94	0.11	53.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	10.46	306.13	310.73	1313.32	329.39	10661.10	437.89	159.65	321.92	21.41
12	30.53	112.91	10.19	222.49	171.21	2317.91	14.18	220.06	59.53	21.64
13	44.80	37.54	49.88	1235.93	587.03	6409.22	412.09	44.30	302.95	21.39
14	98.04	56.79	7.08	644.22	1152.11	4020.70	221.51	511.25	162.01	21.52
AVERA	43.17	63.79	127.68	806.95	312.70	3043.20	315.95	226.58	232.28	21.48

Figure 14

AD P001229

DESIGN TO COST UNDER CHANGING PROGRAM CONDITIONS

"NOTHING IS PERMANENT BUT CHANGE"
Hiraclitus (c. 500 B.C.)

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Introduction

The complex process of fielding a new defense system is characterized by a number of factors which frequently cause changes to the originally conceived plans. Changes in the military threat to be addressed, priorities, available resources, allocation of these resources, and a host of other considerations provide a dynamic rather than a static environment for the development, production and fielding of a new system. Despite our efforts to stabilize programs, this dynamic environment is manifested in changes to program quantities and rates of production for a system during its development and production phases.

Department of Defense Directive 5000.28,[1] titled "Design to Cost" requires that Design to Cost (DTC) goals be submitted as part of the normal program review milestones, and that these goals be supported by applicable rationale such as quantities, production rates, and cost/quantity relationships. Given the dynamic nature of the programs, the question arises as to what effect the program changes have on the DTC goals. This paper proposes a method for adjusting DTC goals under conditions of changing program quantities and/or anticipated production rates.

The DoD Product Engineering Services Office (DPESO) has developed a cost model[2] which relates unit cost to cumulative quantity produced and production rate per year. These three variables are depicted as a three dimensional response surface. The model provides planning information of sufficient accuracy to assist in estimating the effects of various production rate profiles, and would appear to have application in the design to cost arena.

The Rate/Cost/Quantity Model

Traditionally, system costs have been projected using the familiar experience curve. This method depicts the projected unit cost as a function of cumulative quantity produced, without regard for the production rates involved. The rate/cost/quantity model discussed here adds production rate as the "Z" axis of a three-dimensional response surface (Figure 1).

Data inputs for this model consist of historical rate/cost/quantity data for ongoing programs or cost estimates for new programs. Only recurring hardware costs are considered, not total program costs. A multiple regression is performed in which unit cost is the dependent variable and cumulative quantity and production rate are the independent variables. By this method, an equation is derived which describes the three-dimensional response surface relating these variables. Most of the sets of historical data analyzed in this manner to date have shown a high multiple correlation coefficient (in excess of 0.9).

Figure 2 depicts the response surface for a hypothetical weapon system and will serve to compare the experience curve method with the rate/cost/quantity method.

Given:

- O First unit cost = $1000 for a rate of 600 units/year
- O 90 percent experience curve slope (exponent -.152)
- O 85 percent rate/cost curve slope (exponent -.235)
- O 6000 units to be produced

Experience curve method:

(1) $\underline{\text{Unit Cost} = AX^{-B} = 1000\ X^{-.152}}$

Rate/cost/quantity method:

$$\text{Unit Cost} = (A)\ \text{Quantity}^{-B}\ \text{Rate}^{-C}$$

Using first unit cost data point to solve for A:

$$1000 = (A)\ 1^{-.152}\ 600^{-.235}$$

$$A = 4482$$

Therefore:

(2) $\underline{\text{Unit Cost} = 4482\ Q^{-.152}\ R^{-.235}}$

When equation (1) and equation (2) are used to project unit costs versus cumulative quantity at a constant production rate of 600 per year, the results are identical. When equation (1) and (2) are used to predict unit costs for a variable production rate the results are shown in figure 3. As can be seen from this figure, the lower unit costs are associated with the higher production rates, and the higher unit costs are associated with the lower production rates.

Expanding on this concept establishes the following relationships:

IF: $\text{Unit Cost} = A\ Q^{-B}\ R^{-C}$

Where: A = The intercept of the response surface with the unit cost axis
Q = Cumulative quantity produced
-B = The quantity/cost (experience curve) exponent
R = Production rate/year
-C = Rate/cost exponent

THEN: Cumulative average unit cost = $\frac{A}{-B+1} Q^{-B} R^{-C}$

AND: Cumulative cost = $\frac{A}{-B+1} Q^{-B+1} R^{-C}$

(Note: The expression for cumulative average unit cost is an approximation. Significant errors may be introduced if this expression is used for quantities less than approximately 30 units.)

Application of the Model to Design to Cost Goal Adjustments

From the rate/cost/quantity relationships shown above, unit cost, cumulative average unit cost, or cumulative cost could be used in adjusting design to cost goals as program quantities and/or rates are changed. In the following example unit costs are used to illustrate the proposed method.

Assume: Unit cost ($K) = $500\ Q^{-.1848}\ R^{-.1135}$

If values for unit cost are held constant, and the equation is solved for corresponding values of cumulative quantity and production rate, the results may be depicted as shown in figure 4.

Figure 4 serves as a framework for illustrating the proposed method for adjusting design to cost goals under changing program conditions. Assume the following sets of conditions for quantities and rates:

	Quantity	Rate/Year	DTC Goal ($K)
Original plan	600	180	85.03
Change #1	500	100	
Change #2	1000	200	

Using the equation for unit cost, new DTC goals may be calculated, and plotted as shown in figure 5. The results are as follows:

Change #1 New Unit Cost = $500\ (500)^{-.1848}\ (100)^{-.1135}$ = $94.01K

Change #2 New Unit Cost = $500\ (1000)^{-.1848}\ (200)^{-.1135}$ = $76.45K

The three points shown on figure 5 may be summarized as follows:

	Quantity	Rate/Year	DTC Goals ($K)
Point 1	600	180	85.03
Point 2	500	100	94.01
Point 3	1000	200	76.45

In establishing DTC goals, initial production quantities and rates are prescribed, and an experience curve negotiated. If a slope for the rate/cost curve were determined, the rate/cost/quantity model could provide a method for adjusting DTC goals as program conditions varied. Rate/cost relationships could be derived from proposal data at different rate/quantity conditions, or from experience on prior programs.

Summary

The PESO cost model was designed to estimate the effects of alternative production rate profiles on unit costs and program costs. Computer programs have been developed and are in use for calculating these results and for displaying the results graphically. This model would appear to have application in determining appropriate adjustments to DTC goals as planned program production rates and/or quantities are changed.

References:

1. Department of Defense Directive 5000.28, May 23, 1975, titled "Design to Cost."

2. Bemis, J.C., "A Model for Examining the Cost Implications of production Rate," Concepts, the Journal of Defense Systems Acquisition Management, Vol. 4, No. 2, Spring 1981, pp 84-94.

3-DIMENSIONAL RESPONSE SURFACE

FOR

RATE/COST/QUANTITY RELATIONSHIPS

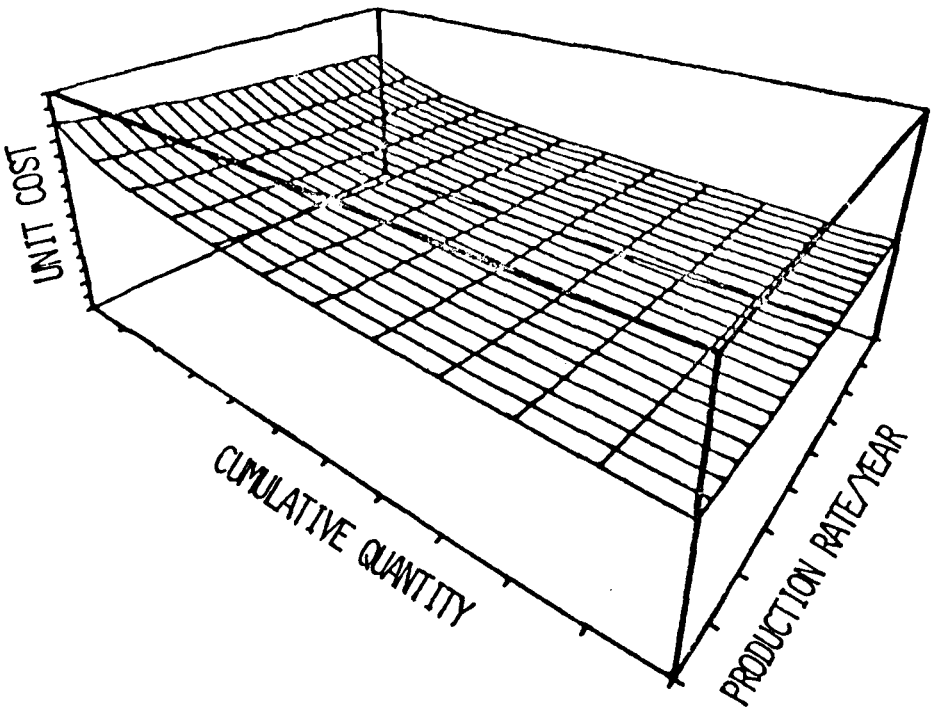


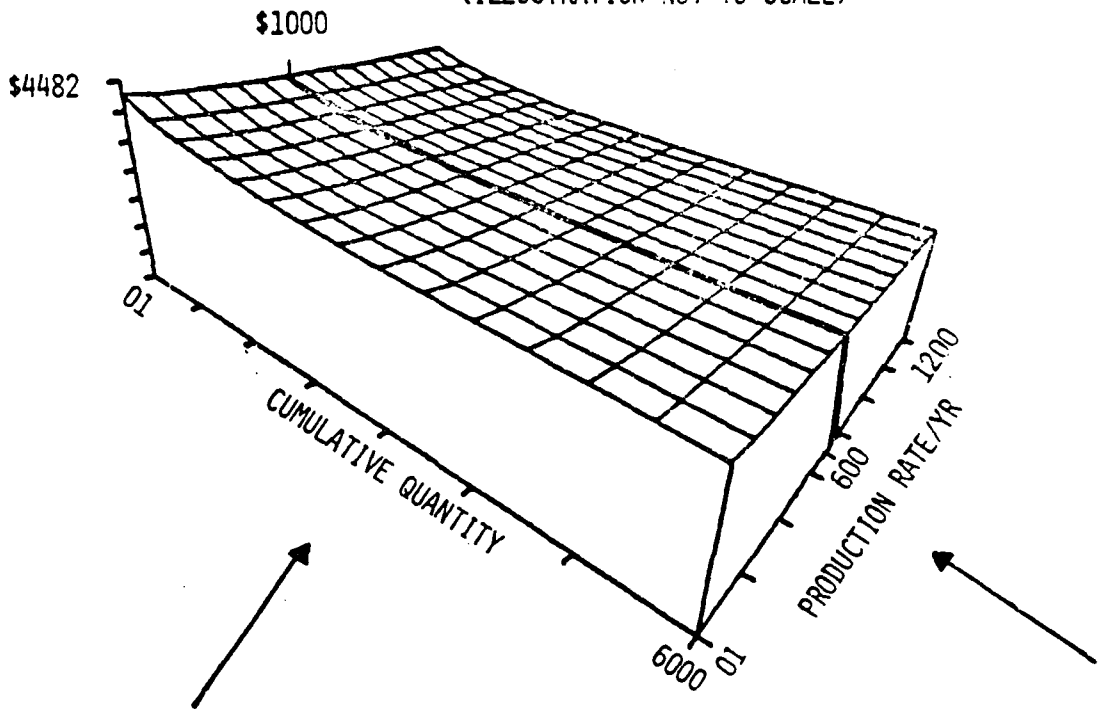
FIGURE 1

COMPARISON BETWEEN CUMULATIVE QUANTITY METHOD

AND

RATE/COST/QUANTITY METHOD

(ILLUSTRATION NOT TO SCALE)



GIVEN: FIRST UNIT COST = 1000 FOR RATE OF 600/YR

90% LEARNING CURVE SLOPE

85% RATE/COST CURVE SLOPE

6000 UNITS TO BE PRODUCED

CUM. QUANTITY METHOD:

$$Y = AX^B = 1000\ X^{-.152}$$

RATE/COST/QUANTITY METHOD:

$$Y = K\ Q^{-.XXX}\ R^{-.XXX}$$

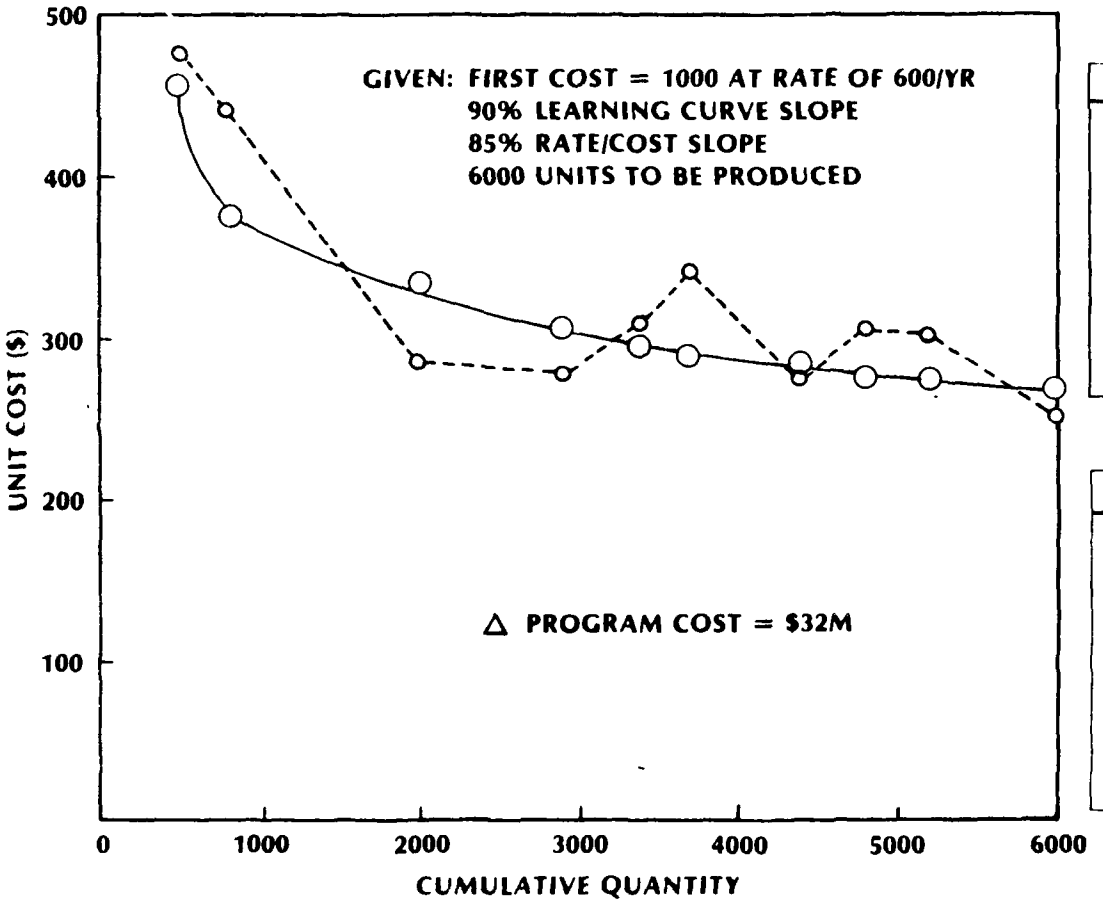
USING FIRST UNIT COST DATA POINT:

$$1000 = K\ (1)^{-.152}\ (600)^{-.235}$$

$$K = 4482$$

$$Y = 4482\ Q^{-.152}\ R^{-.2345}$$

FIGURE 2



○ RESULTS FOR Y = 1000 Q -.152

UNIT COST	YEARLY COST	QUANTITY	CUM QTY
457.5525	228776.2	500	500
374.1584	112247.6	300	800
334.3567	401228.3	1200	2000
305.6545	275089.2	900	2900
293.9675	146983.8	500	3400
288.6455	86593.69	300	3700
282.9568	198069.8	700	4400
277.4951	110998.1	400	4800
273.9985	109599.5	400	5200
269.3386	215471.1	800	6000
314.1758	1.885055E + 06	6000	

○ RESULTS FOR Y = 4482 Q -.152 R -.2345

UNIT COST	YEARLY COST	QUANTITY	CUM QTY
477.5334	238766.7	500	500
440.1917	132057.5	300	800
284.1904	341028.6	1200	2000
277.9268	250134.1	900	2900
306.8059	153403	500	3400
339.5862	101875.9	300	3700
272.9077	191035.4	700	4400
305.1716	122068.7	400	4800
301.3259	120530.4	400	5200
251.7643	201411.4	800	6000
308.7178	1.852308E + 06	6000	

FIGURE 3

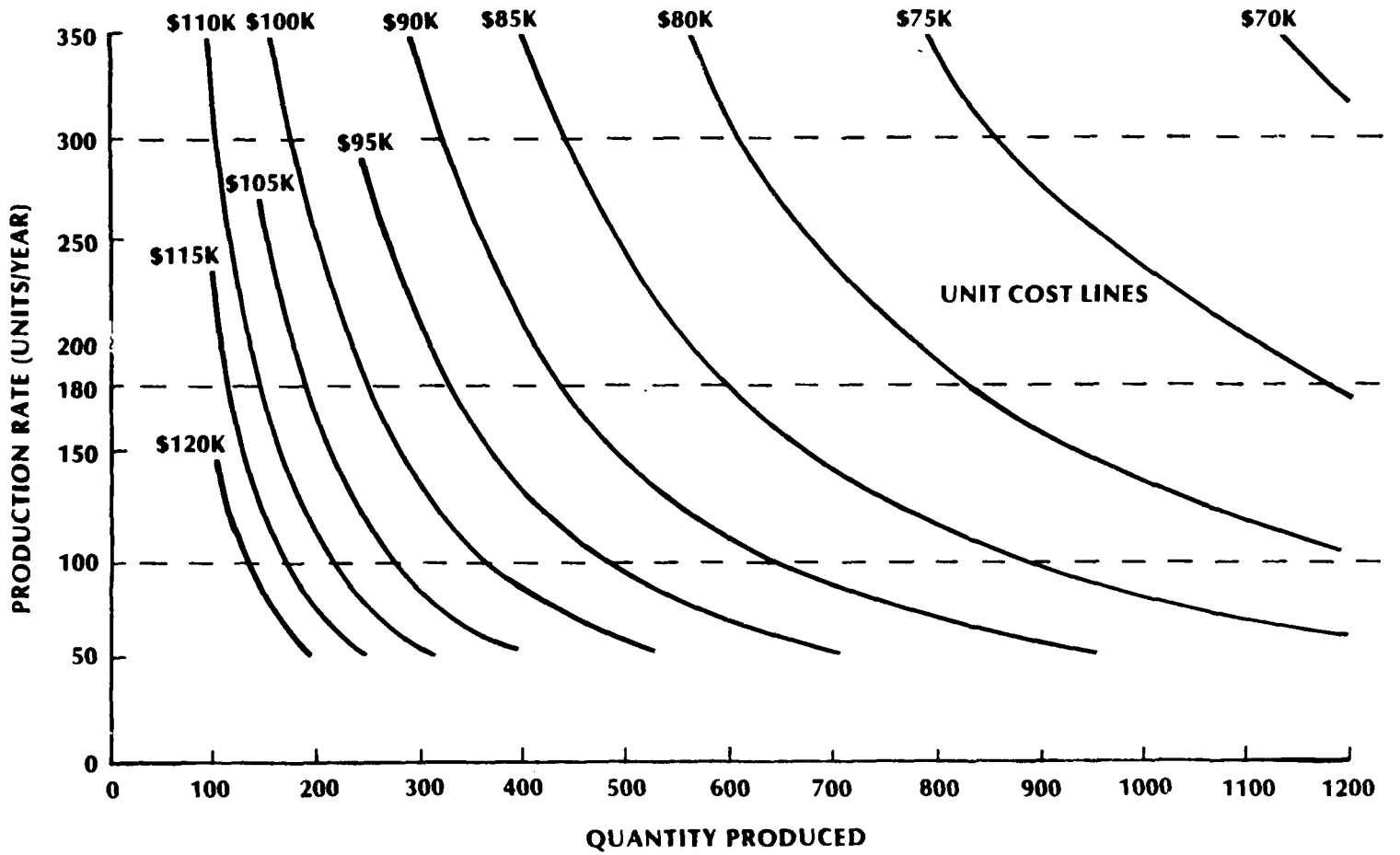

$110K
$100K
$90K
$85K
$80K
$75K
$70K
$95K
$105K
$115K
$120K
UNIT COST LINES
350
300
250
200
180
150
100
50
0
PRODUCTION RATE (UNITS/YEAR)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
QUANTITY PRODUCED

FIGURE 4

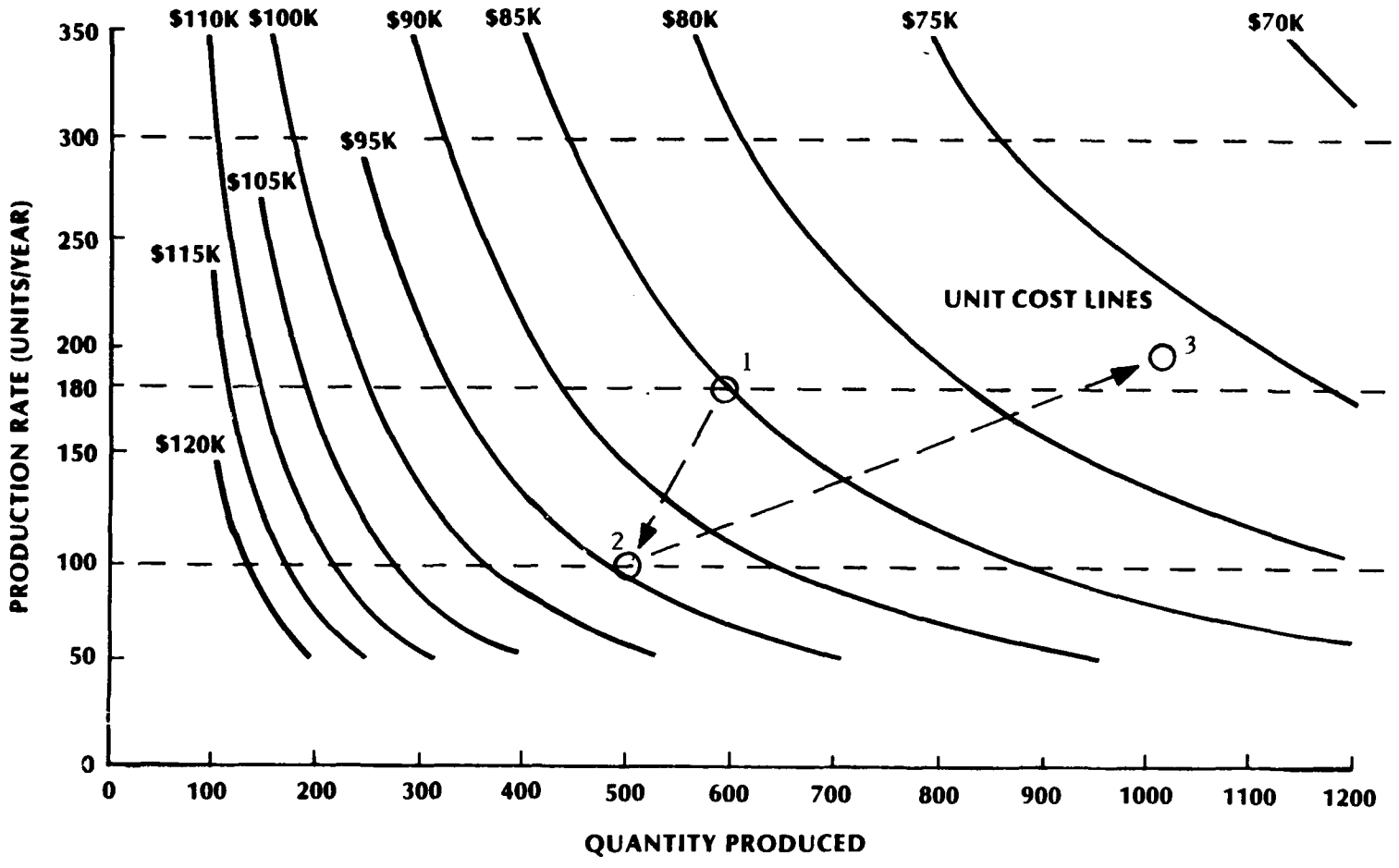

$110K
$100K
$90K
$85K
$80K
$75K
$70K
$95K
$105K
$115K
$120K
UNIT COST LINES
1
2
3
PRODUCTION RATE (UNITS/YEAR)
350
300
250
200
180
150
100
50
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
QUANTITY PRODUCED

FIGURE 5

AD P001230

EXPERIENCE CURVES ON FIVE ARMY PROGRAMS

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Introduction

Previous investigations of competitive defense acquisition policies have used an ex post methodology. They have relied on aggregate cost histories of past programs where a second source had been introduced at some time subsequent to the initiation of sole source production. Analysts have assumed that firms set price for successive production lots by means of an experience curve. This is a functional relation between either unit price or the average unit price and the nth unit of cumulative output, or the average of n units of output. It is usually represented as a constant elasticity relationship. The major finding regarding the effectiveness of a competitive acquisition policy are equivocal but it can be safely stated that at some time subsequent to the introduction of a second source: (1) There is an abrupt decline, or translation, in the unit cost from what would have occurred if there were continued use of a sole source; (2) The rate at which costs are reduced with cumulative output as successive competitions are held is higher than the previous sole source rate. Interpretative ambiguities are principally about the magnitude and duration of the effects. Disagreement

also occurs because of large and possibly systematic measurement errors, the smallness of the sample size and the excessively large dispersion of the competitive outcomes.[1] It would seem that a much more complex analytical model is necessary to explain observations.

There is a supplementary approach that should provide a basis for identifying the sources of the large variance in competitive outcomes. This is to adopt an ex ante method: to determine how sole source and competitive contractors actually derive and use experience curves in their pricing and resource management. If the introduction of competition has a significant effect on acquisition costs, then the source of the potential savings should be visible in the manner in which sole source and competitive contractors plan and conduct their operations. Thus, this paper summarizes how contractors used experience curves for five current Army acquisition programs: the Bradley Fighting Vehicle System, (BFVS); the Multiple Launch Rocket System, (MLRS); the Copperhead artillery projectile, the Viper anti-tank rocket, and the York Division Air Defense Gun System, (DIVAD).

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[1] A recent summary of research on competitive acquisition is: K.A. Archibald, et.al., Factors Affecting the Use of Competition in Weapon System Acquisition, RAND Corporation R-2706-DR&E, February 1981. See Paul M. Carrick, The Uses of a Competitive Acquisition Strategy: An Investigation of Five Army Programs, Institute for Defense Analyses, to be published in the Fall 1982, Chapter III, for a more theoretical and inclusive review.

For each of the five programs, the prime contractors were questioned on the derivation and the scope of use of experience curves. What previous program experience did the contractor use for estimating the parameters of his experience curves? What level of disaggregation was followed in estimating specific curves? How did he use experience curves in project management? Since economies associated with changes in the rate of production provide an alternative, or supplementary, hypothesis for explaining changes in unit costs, the contractors were also questioned on how the rate of production had been established.

The role of experience curves on the five programs will be developed in four steps. First, the current state of the art regarding contractor and DoD use of experience curves, as reflected in the five programs, will be summarized. Since the determination of the rate of production has an important factor in shaping contractor performance on the five programs, it will be discussed next. Thirdly, the substantial differences in contractors' assumed experience curves will be considered. This topic leads into analysis of not only accounting procedures but also the role of industrial engineering. Lastly, the differences in contractors' cost estimation practices are discussed.

Summary of Findings

It probably is best to state at this point some of the major conclusions that are drawn from the investigation. In general, the competitively induced changes in the height and slope of contractors' experience curves can be traced to the poor workability of DoD's promulgated rules,(i.e., the DAR), for managing an economy by negotiation. There is sufficient permissiveness in the rules and in the manner in which a firm may implement them that the introduction of competition may result in large price reductions. It is difficult to make a general statement as to the magnitude, composition and timing of price reductions. In some instances, the major source of expected savings will occur from a shift to lower cost labor - a one time saving. In other cases, the major source of expected savings arises from adoption of more efficient production technology. In this instance, the competitive savings should be distributed over several years at least. In general, the effects of introducing competition should be nearly completely realized within five to seven years. Subsequent cost experience should then reflect the general technological progressiveness of the economy, i.e., the growth rates in output per worker or output per factor input for all manufacturing.[1]

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1 For recent industry performance measurements see John W. Kendrick "Productivity Trends in the United States," in J. Kendrick and B. Vacccara, eds., New Developments in Productivity Measurement and Analysis, University of Chicago Press, 1980, pp. 9-30.

It should also be pointed out that the DoD practice of making the award of a sole source FPI production contract an integral part of a prototype competition is not a panacea. It can not be regarded as a good substitute for continuing competition into production. Besides confounding the criteria used in selecting the winner of a competitive development, neither competitor typically possesses sufficient information to accurately estimate production costs. On one program, the DIVAD, the winning contractor had not yet even designed at the time of the competition a number of equipments whose cost production he was required to estimate. Again on the DIVAD prototype competition, the losing contractor estimated the cost of setting up an ammunition production facility as only 20% of the amount the winning contractor proposed. In the competitive development phases of the Viper and Copperhead programs, neither of the winning contractors adequately understood the technology underlying their design much less the exceptional difficulties in defining and implementing a high rate production technology. In the case of the MLRS competition, the contractors were required to estimate inflation rates for the subsequent five years in forming their bid prices. The winning contractor, along with almost all economic forecasters, appears to have overestimated the rate of inflation by more than a factor of two. Such windfall profits serve no useful economic purpose.

Experience Curves in Program Planning

Every defense contractor has to be familiar with the concept of an experience curve, even if he does not use it explicitly in his production planning. All defense contractors are required to use a Design to Unit Production Cost (DTUPC) concept in their program planning since the DoD Directive 5000.28, Design to Cost, was issued in May 1975. A DTUPC is to be an "average unit flyaway, or rollaway, cost." Further, DoD Instruction 7000.3 of April 1979, Selected Acquisition Reports (SARs), requires that all large acquisition programs use a cost-quantity curve in defining a DTUPC value.

Production RFPs for some of the five Army acquisition programs were reviewed to determine how these instructions are actually implemented. Quotations from a few of these RFPs indicate what kind of cost information the contractor must be able to provide to the government.

The DIVAD production RFP, issued May 8, 1980, is a four inch thick document with small closely spaced type. The gist of the cost information requirements imposed on the two competing contractors can be gathered from the following quotations:

> "The price quoted for the target...quantity on each stand-along DD633/DAR 16-206 will also be the price quoted for any quantity which varies by ± 10% from the quantity..."[1]

[1] DAAK 10-80-R-0027, p. 59, paragraph C.4. 1.1

"The offeror will submit [for each of two production schedules] his UPC [unit production cost] estimates... for each level of buy (first year plus each option) and explain how the UPC was derived and shall list the assumptions that were made in preparing the estimates. The cost development shall include:

(a) Sources of historical data; i.e., company's historical data and vendor quotes. Use of historical data will require documentation and treatment of cost trend...

(b) Use of learning curves bases on unit theory with theoretical first unit cost and slope...

(c) Assignment of UPC goals to major subcontractors...

(d) Identification of critical components, materials and processes that will be given special emphasis.

(e) Production rates upon which UPC is based.[1]

"Prepare a list of actual trade-offs reflected in the proposed UPCs, including significantly increased performance at a minimal increase in cost and minimally reduced performance at a significantly reduced cost..."[2]

A second illustration of the kind of cost information defense contractors are expected to be able to provide is taken from the RFP given to the two competitors for the MLRS production contract award in August 1979. This RFP is noteworthy for its focus on the sensitivity of unit production cost to the assumed production rate.

A contractor is to have an explicit management system for control of the Design to Unit Production Cost (DTUPC).

"The plan must be capable of detecting, recording, reporting, and explaining...any changes in any of the bases upon which the original design-to-cost was estimated, including: the learning curves (types and slopes); labor and overhead rates; anticipated labor efficiency factors; anticipated material scrap factors..."[3]

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[1] DAAK 10-80-R-0027, p. 62, paragraph C. 4. 3. 1.

[2] Ibid., p. 63, paragraph C. 4. 3. 5.

[3] Solicitation No. DAAHO1-80-R-0017 August 1979, p. 59.

For a stated monthly production rate and total program procurement quantity, a contractor is to:

> "...propose design to production costs...as a minimum at the 4th level [of the Work Breakdown Structure] for the Air Vehicle and Launch Pod Container and 5th level for the self-propelled launcher loader."[1]

For each element of the Work Breakdown Structure, the contractor is required to provide:

> "An indication of how the proposed cost was derived; e.g., historical data, engineering or parametric estimate, vendor quote...if improvement slopes are used in generating integral parts of proposed DTUPC costs...historical data on applicable programs' items...shall be included."[2]

But a most unusual feature is the request for cost-production rate sensitivity data:

> "The contractor shall further provide as a part of the IPF [Initial Production Facilities] cost proposal a separate unit cost versus production rate sensitivity graphic display for each hardware element at level 2 of the production Work Breakdown Structure. The hardware recurring unit cost (i.e., manufacturing cost) sensitivity to production rate will be displayed using as a baseline the established DTUPC values. The recurring costs will be based on the assumption that the hardware build rate on a 2-8-5 basis is equal to the rate for which the tooling and test equipment was designed."[3]

The sensitivity of the unit cost component is to be estimated for production rates varying from zero to 11,000 units a month, for only the rocket vehicle.

The third and last example of what is really the existing state-of-the-art in production cost estimation is taken from the recent competition for selection of a second production

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[1] Solicitation No. DAAH01-80-R-0017 of 22 Aug. 1979, p. 62.

[2] Ibid., p. 63.

[3] Ibid., p. 600.

source for the BFVS. Bidders are required to provide:

> "Hardware unit cost will be prepared by WBS elements for each procurement quantity...separate learning curve formulas on labor and material will be provided together with any other cost/quantity relationships used in developing the estimate. The data base used in developing learning curves will also be provided."[1]

The solicitation specifies a basic production rate of 50 vehicles a month. A bidder is required to:

> "Provide cost penalties for low rates of production (defined as 30 vehicles per month and 20 vehicles per month or less). Penalties shall be categorized if possible [in a specific level of detail] as a percent of recurring cost."[2]

Additionally, a bidder is to provide a cost estimate "for the incremental tooling/facilities...to achieve a vehicle production rate of 90 per month..."[3]

The Role of Subcontractors' Curves

Most analysts of competitive acquisitions have treated a prime contractor's gross annual sales as the basic set of observations for estimating parameters. Several of the five prime contractors surveyed have promulgated experience curve slope values which imply that they make their analyses of their own program cost history at this high level of aggregation. However, upon questioning, it was determined that these contractors obtained aggregate values as a weighted arithmetic mean of the more finely detailed cost-quantity values as required by

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[1] Solicitation No. DAAE07-81-R-0005, No date, Exhibit D.

[2] Ibid., Exhibit C.

[3] Ibid., Exhibit G.

the usual RFP terminology. Particularly, subcontractors' experience curves do form a separate set from the prime contractor's curves in derivation of an annual total production cost estimate.

In the five programs reviewed, the practice of separating the primes' from the subcontractors' experience curves is most vividly illustrated by the FMC Corporation's cost estimates for the FVS. In 1978 the company was tasked by Congress to provide a detailed justification of the total procurement cost of the FVS. The resulting "Gold Book" of June 1979 is a model for completeness. Since it is Contractor Private Data, no values will be quoted from it. Suffice it to say, however, that each major subcontractor provided an independently derived program cost estimate for the portion of the FVS hardware for which he was responsible. Experience curve slope values ranged from the mid 80's to the mid 90's percent.

There is an important policy lesson to be drawn from this practice. It is standard DoD practice to hold the prime contractor responsible for all negative excursions from expected progress on a program. In fact, most information that flows upward from a program office is in such an aggregated form that it leads one to hold a prime contractor responsible. But, to take the FMC cost break-out information as an example, while it is a simple matter to fit an experience curve to the FMC Corporation's annual total production cost data, the resulting

function can support only very limited inferences. With the passage of time the percentage contribution of any subcontractor to total cost will change systematically, the direction depending on how the slope of his experience curve is related to the average slope value for the total cost of production. Thus, if the slope of a prime contractor's aggregate experience curv is believed to be too shallow, rather than introducing a second prime contractor to interface with the same subcontractors, a more productive policy might involve establishing second sources for one or more of the subcontractors. Previous analyses of competitive acquisition have neglected to consider this policy alternative. This has most probably been because of the lack of pertinent data.

Interaction of Experience Curve and Production Rate Requirements

Most investigations of the relationship between unit cost and the rate of production have found constant economies of scale. That is, the unit cost of production is constant for all production rates above some minimum firm size.[1] The conclusion is based upon cross-sectional studies of sub sets of firms' costs or profits whose product lines, as defined by census practice, places them in the same industry. Increases in factor productivity are, therefore, assumed to be independent of the size of

[1] H.J. Goldschmid, H.M. Mann and J.F. Weston, eds., *Industrial Concentration: The New Learning*, Little, Brown, 1974, pp. 16-54. See also: Peter F. Cory, "A Technique for Obtaining Improved Proxy Estimates of Mimimum Optimal Scale," *Review of Economic and Statistics*, 62, February 1981, pp. 96-106, and S. Davies, "Minimum Efficient Size and Seller Concentration: An Empirical Problem," *Journal of Industrial Economics*, 28, March 1980, pp. 287-301.

the firm. Following this line of reasoning, the values of the parameters of a firm's experience curve should be independent of the scale of production at which it is designed to operate.

Graphically the locus firms' constitute a L-shaped curve. By implication, therefore, the correct representation of scale and cumulative production quantity effects is as an additive function.

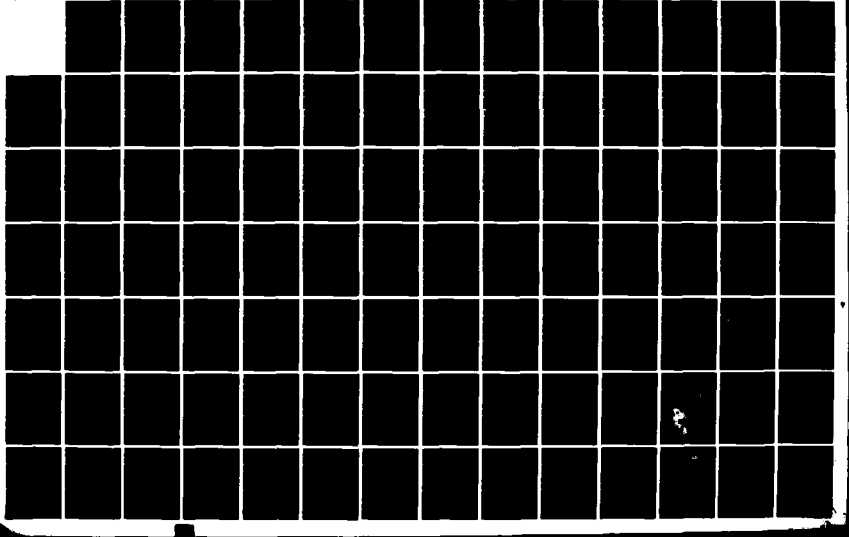
But it is important not to push the assumed independence and constancy of scale effects too far. First, the economic investigations have concentrated on cross-sectional industry studies. No studies of firms' cost are known to have used a longitudinal approach, as required for a study of a cost-cumulative output relationship. Secondly, there is a difference between a firm's economies of scale where all production constraints are assumed non-existent, and production economies, where they are not.

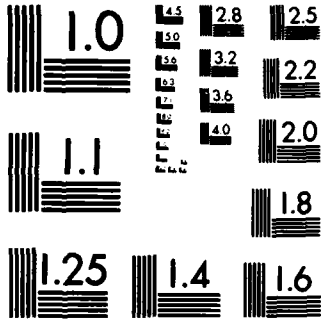
The production reality in defense contracting is complex. Few new production facilities are designed and constructed just for a single new program. Usually, a contractor will add to his existing production capabilities or bring in subcontractors who already possess the necessary production facilities. In fact, it is not incorrect to point out that a product's design will usually reflect the contractor's existing production capabilities since cost estimates can be more easily formulated in this case.

Thus, the expected a priori relationship between the rate of production and the effects of production experience may not be a simple linear one.

AD-A130 418 DEPARTMENT OF DEFENSE ANNUAL COST ANALYSIS SYMPOSIUM (17TH) HELD AT ARLINGTON VIRGINIA ON 12-15 SEPTEMBER 1982(U) OFFICE OF THE CHIEF OF NAVAL OPERATIONS WASHINGTON DC SEP 82 3/6

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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Of the five acquisition programs, four involved almost entirely new facilities for the final assembly of the product as well as for several of the major subcontractors. These four were the Viper, MLRS, DIVAD and the Copperhead programs. But even this should be qualified. General Dynamics has been able to use on the Viper program some of the facilities that were acquired for the Stinger missile production. Again, the Martin Marietta Co. uses its electronic and optical production capabilities for meeting the production requirements for several other programs. In the case of the MLRS program, the Vought Co. has refurbished a former Navy Ammunition Plant in Camden, Arkansas for its rocket production, while the launcher-loader is to be produced at the company's Irvington, Texas plant, using space that has been used for A-7 aircraft production.

When a bidder for a government production contract plans to rely upon his existing facilities, then certainly there should be a small band in the feasible production rates which will allow him to produce at the lowest unit cost. Even then, however, the upper limit of the low cost production rate segment can be significantly raised by a contractor relying on subcontractors rather than in-house production. It is only when a contractor, or several of his larger subcontractors, already have substantial excess production capacity that one should expect a drastic reduction in unit production costs with an increased rate of production.

It is instructive to determine how the nominal production rate was determined for the five acquisition programs. On the BFVS, for example, when the Program Office first raised the issue, the prime contractor (FMC Corporation) already had outstanding production commitments on several other programs extending over the next few years. The contractor suggested that the 50 vehicle per month production could be accommodated in existing facilities. From interview information, the contractor currently believes that his unit cost of production would be relatively constant over a range from 30 per month to 90 vehicles per month. This should not be taken to imply the contractor will not need additional production capability to meet the higher rate or that he will not have idle capacity at the lower production rate. Both conditions would hold, but the effect on unit cost would apparently be negligible.

On the DIVAD program, the rate of production appears to have been derived by extraneous considerations: the highest rate at which the vehicle could be inserted into the peacetime Army force structure. Whatever the rate of production, the prime contractor still requires a very extensive facilitization investment. The Army is investing over $140 million in DIVAD production tooling and facilities while the Ford Company is investing over $50 million of company funds. It seems unlikely that unit production costs could be significantly lower for either a slightly higher or lower rate of production because of the limited duration of planned production. However, there is no simple means to verify the conclusion and the

issue was not addressed explicitly during early program planning.[1]

During the competitive prototype development phase of the MLRS contract the two firms were formally asked to supply information on the sensitivity of unit cost to the rate of production. But this request was too late in the program to influence the choice of the rate of production. By the time of the competitive shoot-off, the two contractors were asked to make commitments on FPI contracts that called for a nominal 6000 rockets per month. Thus, the possibility of creating a competitive industry structure, with firms sized to produce 2000 to 3000 rockets per month, was not investigated. The MLRS contract terminology on cost sensitivity quoted above represents after-the-fact information. The Army already had a signed FPI contract with the winning contractor before they were in a position to analyze the information.

The vagaries in the determination of the rate of production for the Copperhead and Viper programs are instructive. Over a three year period the prime contractor on the Viper program was successively asked to provide cost estimates for producing 1,700,000 rockets at six different monthly rates: 91,000 per month, 10,000 per month, 25,000 40,000, 13,000 and 1,400 per month. The process of sizing the production base occurred concurrently with the full scale engineering development, so as technical problems arose and

[1] The Ford Aerospace and Communication Corporation management recounted to the writer that the home office greeted their request for investment funds with disbelief. A total production of 618 units, the entire DIVAD program buy, seemed insignificant to managers who who were used to planning for production rates of 1000 units a week.

the anticipated total program production cost changed, upward usually, the planned monthly production rate was modified by the Army Program Manager. As a result of this sporadic change in planned production, two subcontractors have invested their company funds in facilities sized to produce at 25,000 per month. All others, including the prime contractor, have invested in production capabilities sized to produce at 10,000 per month. The most recent planned acquisition rate is 1,400 rockets per month.

The Copperhead program illustrates another extreme in production planning. The original conception was that 133,000 units would be produced at a rate of 3,000 per month. However, the Army found the estimated tooling costs for such a facility would be excessive and accordingly scaled down the production rate. After several iterations, a production rate of 700 per month was decided on. The prime contractor, as well as the major subcontractors, then began to invest company, and government, funds in production capabilities sized to produce at the rate of 700 units per month. It appears unlikely at present that monthly production will ever exceed 400 a month. Further, the total buy quantity will probably be less than 50,000 units.

The implication of these two illustrations as regards a competitive acquisition policy should not be overlooked. In both cases, certain subcontractors have invested in facilities to support production rates far in excess of their facilities' likely utilization.

A second source, if sized to some much smaller production rate, could doubtlessly produce at a lower cost. If a split-award or winner-take-all competition were to be conducted, significant price reduction could probably be induced. But any such observed price reduction are economically meaningless. For the split-award case, the average production cost would probably still be higher, or at least as high, as if all facilities had been sized to the smaller actual procurement rate. Further, a winner-take-all competition would tend to discourage future investment in production facilities since the original expectations were allowed to become so at variance with reality.

It will be recalled that the earlier review of competitive acquisition policy emphasized the remarkably large dispersion in outcomes. How many of the extreme cases had similar antecedents to the Viper or Copperhead programs? How had the facility sizing decisions been guided in those cases where the introduction of competition resulted in such large savings? The questions cannot be answered since the original researchers did not ask them. But it is apparent that an ex post evaluation of competitive acquisition policy should not be made solely in terms of the expected experience curves.

Contractor Practice in Derivation of Experience Curves: Accounting Practices, Management Controls, and Incentive Effects

It should be explicitly acknowledged that no contractor derives an experience curve directly. Some companies' sales brochures may

imply this is the case but it should be discounted. Rather, contractors work with learning curves. They conduct their analyses and prediction in terms of direct inputs, particularly direct labor hours. By assuming a production rate, they arrive at a total cost of production, which includes direct and indirect costs. Indirect costs are expressed as a percentage value since contractors' indirect expenditures are recovered through a "quote rate" arrangement. Thus, indirect costs are effectively converted to direct costs for contract price determination. The effect is, then, that a contractor can logically move from his learning curve to an experience curve quite easily.

What is called a direct cost is partly a matter of judgment and contractor practice. It should be recalled in this context that defense contractors' indirect costs, measured as a percentage of total costs, have been increasing over the last ten years. Often, this is charged to a practice of employees taking a larger share of their wage increases in non-taxable benefits such as medical insurance or pension contributions, which are customarily treated as indirect charges. However, no one has actually investigated why this relative increase in the importance of indirect costs has occurred. An alternative hypothesis is that contractors' direct charges have been subject to far greater scrutiny, reporting and control over the last decade. The pervasive use of learning curves illustrates the point. Thus, in order for contractors to adjust their observable direct charges to conform to the learning curves predicted values,

it may be necessary to substitute resources in production that can be charged off as indirect costs.[1]

The way in which DoD defines the method for recovery of indirect costs most probably also distorts business incentives.[2] If DoD had a different practice for controlling the recovery of indirect costs, then the experience curve that would be subsequently measured might be quite different. How the parameter values might differ can only be conjectured, but it is likely that some method for recovery of indirect costs can be defined which would result in lower production costs. In summary, the cost accounting data available from either sole source or competitive procurements are shaped by the conventions that are used in defining indirect costs and which control their assignment to direct cost values for purposes of indirect cost recovery.

A learning curve, or experience curve, should be seen for what it really is. It constitutes a management device that DoD, having discovered, has imposed on contractors as a cost estimating and reporting requirement. A contractor will have to manage his production program so that unit costs conform to the prediction.

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[1] The topic of the relationship between measurement practice and a possible distortion of incentives is too vast to do more than mention its existence. The field is quite new and ill-structured. See, for example, J.L. Zimmerman, "The Costs and Benefits of Cost Allocations," *The Accounting Review*, 54, July 1979, 504-421.

[2] The most flagarent distortion of contractors' incentives is undoubted caused by the non-allowability of interest payments as a cost of doing business. Because of this, DoD has had to become the defense contractors' banker insofar as it makes progress payments. Other incenti distorting accounting practices exist in the DAR implementation. Several Cost Accounting Standards must have such an effect. Thus, the effect of the indirect cost recovery method is embedded in a very large set of other incentive distorti accounting practices.

The values deduced from a curve are not real except in a limited or normative way. A contractor has considerable incentive to start off a program with a high assumed first unit cost and a shallow rate of predicted improvement.[1]

Experience Curves and Industrial Engineering

There is a long tradition in American industry of using Industrial Engineering, or motion and time studies, to define efficient labor usage. Most defense contractors have Industrial Engineering Departments that publish such labor hour budgets by industrial process. The strange thing about this practice is that it is antagonistic with the use of learning curves. A learning curve implies that the best labor practice cannot be found immediately and one must be content with merely watching its evolution with continued production. A more general view of the process has been recently suggested. Normally, it is held that the existence of significant learning with continued production represents an economic compromise at work. The cost of a thorough estimation of efficient production would normally exceed the subsequent cost reduction compared with a more cursory exploration. Thus, it is most economical to start producing

[1] In investigating how prices had been formulated in a competitive acquisition, the management of the winning company passed on some useful information. They always prepared bids on competitive acquisitions of new products by deliberately proposing only part of the total tooling costs that they knew would be necessary to permit achievement of the lowest unit production cost. Since RFPs were usually for a single year's buy, instead of a multi-year buy quantity, the company could demonstrate a winning first unit cost and continual cost reduction as they procured the additional tooling on subsequent buys.

quickly with inefficient methods and to then gradually adopt the more efficient methods as they are discovered through on-the-job work efforts. It is only when a large capital investment is required to initiate production that it pays to expend the effort to discover the most efficient production method before starting production.[1]

Relationship Between Experience Curves and Industrial Engineering

Only one case has been found in the survey of prime contractors' usage of experience curves where the contractor had integrated the experience curve with the industrial engineering production standards. The industrial engineers' production times are invariably far below the actual times required. It is largely for this reason that industrial engineers are regarded with such suspicion by factory personnel. One company combined its assumed learning curve slope with the industrial engineering standard to define what it called "a realization factor." When the actual direct hours required in a production department equaled the industrial engineering standard, the realization factor was said to be equal to 100 percent. The company used the current realization value as a basic management tool. Its value was prominently displayed in the

[1] The point is taken from C.F. Pratten, *Economies of Scale in Manufacturing Industry*, Cambridge University Press, 1971, pp. 3-19. Some recent defense production experience confirms this insight. Both the F-15 and the Stinger missile are produced with greater usage of automated equipment than were their predecessor weapon systems, the F-4 and the Redeye missile. Production learning curves for direct labor hours are reported to have a comparatively much more shallow slope. Still, semi-conductor production is probably the most highly automated production today, and semi-conductor firms typically set future prices on a 70 percent learning curve.

factory where workers could easily see how their department compared to other departments in achieving a higher realization rate.

This same company also assumed its learning curves would contain at least one discontinuity. During early production the rate of learning was assumed to be quite high, i.e., the slope was given a value in the 80 percent range. After a certain unspecified amount of cumulative production, or passage of calendar time, the slope was assumed to change to a value in the low 90's. Other than a small sample of past program experience that tended to support this procedure, it also seemed that the company wanted to assure that the predicted unit cost from the experience curve approached the industrial engineering standard asymptotically.

No other instance has been found where a learning curve is used as a micro-management tool. Other companies certainly have a Contractor Cost-Schedule Performance Reporting System (CS)[2] installed and commit a significant quantity of effort to collect the appropriate information. The cost norms in this system should be consistent with the learning curve assumed in the company's original DTUPC cost estimate. However, of the five programs surveyed, only the Martin Marietta Company, the prime contractor for the Copperhead projectile, had a significant period of prior production to have accumulated many monthly CPR reports. The learning effects are not easily extracted from the company's reports since production problems have tended to dominate the expected costs.[1]

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[1] Substantial production has also occurred on the BFVS program. The Army would not release the CPR data for OSD use. It is not known how the PMO uses the information for management control.

Cost Estimation Procedure

Prime contractors must normally submit their program cost estimates in support of a planned annual increment of production. Contracts are invariably written as a dollar sales (or cost) total for a specific number of units to be delivered during the year. Subcontractors are required to submit cost estimates to the prime in similar terms. The estimate may appear to be constructed directly from an experience or learning curve. A first unit cost is assumed and with the addition of an assumed value for the exponent parameter, the total annual cost can be obtained by integration. No firms were found that conduct their cost estimation in this simple a manner. Instead, cost estimates are constructed by working backward from the desired delivery schedule to the machine loading requirements and assumed machine availability values. This total cost of production can then be expressed as an experience curve by finding a pair of parameter values that will yield through integration the same total cost value. Alternatively, when the planned output is a continuation of earlier years' production, the previous year's experience curve values play the role of constraints to be satisfied or explained away. If there is a significant change in the planned rate of production, for example, some or all of the differences in average unit cost from the predicted value will be passed on.

The impression should not be drawn that firms' cost estimating procedures consist of a standard and uniform sequence of operations. Considerable differences in estimation practice do exist. A firm's

management may act as if cost estimates are derived in a systematic and objective manner. Many firms' managements will quote their assumed experience curves' parameters without qualification and act as if cost estimates are obtained merely by extrapolation. But when one probes a bit deeper it is apparent that cost estimates are actually obtained by more complex procedures. These are at least analogous to a multivariate statistical model. In fact, the estimation procedures seem to be more complicated than even this in that a variety of constraints may be considered in forming a prediction.

It is not possible to describe a firm's cost estimation procedure more accurately. It is not clear that any company can even accurately describe its own cost estimating procedures in the sense that the company possesses a coherent set of cost estimating relationships which describe the sequence of operations by which a cost estimate is constructed. None of the five prime contractors that were interviewed provided detailed analyses of how his cost estimates were formulated within the company organization. Part of the reason for this might be due to the interviewer not stating his questions with sufficient precision. On the other hand, cost estimation is not an area where firms usually assign their better analytical talent. Nor is it an area that a firm wants the purchaser to be too well acquainted.

A firm may obtain quite adequate cost estimates from its existing organization without management knowing precisely what this

organization is or how it functions in preparing cost estimates. For example, some firms have centralized cost estimation departments. Other companies appear to rely upon a "grass roots" cost estimation method whereby the department that prepares a cost estimate is also responsible for subsequently delivering the output on schedule and at the estimated cost. There is something to be said for both approaches, but in especially the more widely "grass roots" case a resulting cost estimate may be derived in a manner that defies representation by a simple set of equations and constraints.

This view of firms' cost estimating practices has some important implications. The experience, or learning, curve plays a normative role rather than a mere reporting role. It sets goals for management and departures from its predictions have to be accounted for. One would expect, therefore, that rather modest goals may be set. That is, the lower levels of management would prefer to set goals that they could frequently better. Thus, the slope of an experience curve will probably be assumed to be more shallow than it might otherwise be. But higher management is motivated to recognize the possibility for increasing program size by reducing production costs. Thus, even within a firm there are conflicting incentives. There is no a priori reason why in the absence of competitive pressures, these conflicting incentives will result in a firm seeking out the lowest cost production method.

One control technique is used to excess by both the DoD buyer and firms' management. This is an excessive reliance on a company's

past program history for predicting the production costs for a significantly different product. Every company relies solely on its own unique program history for constructing cost estimates. There is no obvious reason why the rate of cost reduction achieved in past programs should occur in a new venture. To some uncertain extent, the production effort on a new program is a continuation of production on previous programs and cumulative output should be defined accordingly.[1] Further, much of the past reduction in unit costs can be better attributed to the elapsed program time or the unique technical opportunities that a specific design presented.[2]

A logical position has been reached in which the experience curve is viewed as an excessively simplistic method for controlling or appraising a firm's cost estimates. Firms are rarely so well administered that all management actions reflect a common goal. The elaborate controls that DoD has created for administering single suppliers through negotiation may result in distorted incentives

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[1] An example from the BFVS "Gold Book" of 1979, referred to earlier, is pertinent. Of all the subcontractors to the FMC Corp. that submitted cost estimates for the 6882 vehicle production run only one firm estimated a constant single unit value. The Cummins Engine Co. provides the diesel motor for the BFVS vehicle. The engine is identical to the commercial product the company sells to truck assemblers in thousands of units per year. The cost of the Cummins engine has increased far less than any other component since 1979.

[2] Investigators of cost reductions in specific commercial industries have found it advisable to discard the concept of a "first unit" and assume that the rate of cost reduction is solely a function of time. See Paul A. David, "Learning by Doing and Tariff Protection, Journal of Economic History, 25, September 1970, pp. 521-600. Of course, the effect of the number of suppliers may dominate any measure of technical progress. See Robert C. Allen, "Accounting fo Price Changes: American Steel Rails, 1879-1910," Journal of Political Economy, 89, June 1981, pp. 512-528.

and equivocal outcomes. It is for these reasons, basically, that introduction of a second source may show significant savings. If DoD and the supplying company's management controls are functioning effectively, then a second source may not result in a significant saving. But when the controls are malfunctioning, introduction of a second source can result in very large cumulative savings. This is because of the long lag time required for a firm to adopt new management and production methods and to invest in efficient production technology.

But it is unlikely that experience curves are going to be supplemented as management techniques very soon. Thus, if an experience curve is to be used, what guidance can be provided from the investigation of the five programs?

Considering the many prime contractors and subcontractors whose use of experience curves has been investigated during the course of the study, the following conclusions appear to be provisionally valid:

(1) When companies base their cost estimates for the production of new products on experience curves with a slope of 90 percent or higher, they are most probably displaying an acute case of risk aversion. Performance should be substantially superior to the assumption.

(2) When companies assume an experience curve's slope of less than the low 80s for a new and expecially complex, product they are most likely exessively sanguinary or have based their forecast on an erroneous analysis of the company's past production experience. Firms that can point to a past instance where the experience curve's slope is in the 70 percent range either had an unusually difficult and expensive production start-up or have failed

to consider that the effects of learning are probably confounded with the effects of an increased rate of production.

(3) Firms that assume the rate of learning will significantly diminish after some finite point of time or amount of cumulative production have probably inferred about as much as is possible from their company's program history.



AD P001231

LEARNING CURVES: A REVIEW

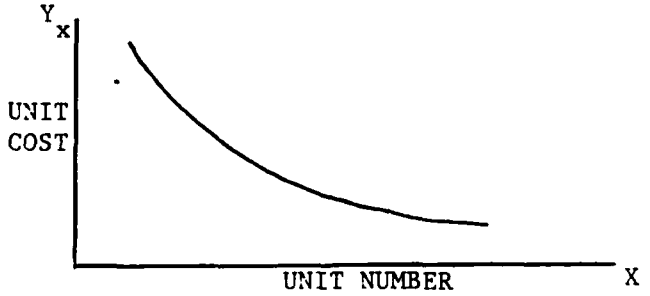
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When forecasting or estimating costs, analyst's are always looking for logical relationships and patterns. These relationships and patterns help us better understand and estimate costs. One of the most widely applied cases where patterns are used involve production. These cases call for use of learning curves.

Learning curve theory states that under certain conditions and due to several reasons, there are patterns in direct costs in a production situation. Several patterns, including the unit, cumulative average, and Cochran's S, have been identified and used in cost analysis. This article discusses the conditions which are necessary for a learning curve pattern to be expected, the reasons for the pattern, and some of the specific patterns that have been noted.

What kind of cost behavior is generally expected with production? We of course expect costs per unit to decrease as more and more units are produced, at least from once production really gets started, to well along in the production run. Now what form will the decrease take? We expect the costs to decrease at a decreasing rate and if we define the unit number as X and the cost of unit X as Y_x then we can graphically indicate our expected pattern as:



and the questions that remain deal with the exact shape of that curve as well as what do we expect at the beginning and at the end of the curve. The various formulations of the learning curve vary primarily as to what is expected at the start of the production and at the end.

Does application of learning curves always make sense? Should their use always be required? The answer is no, of course not. Some insight as to when their use would seem appropriate can be gleaned from the following conditions that seem necessary for reasonable expectation of a learning pattern in costs.

SITUATIONS WHERE THE THEORY

SEEMS TO FIT

- High proportion of manual labor
- Uninterrupted production
- Production of complex items
- No major changes
- Continuous pressure to improve

TABLE 1

While it is true that the learning which occurs, i.e., the lower resources required for items later in production, does not depend solely on the worker, it does seem that learning curve patterns are expected more when we have manual labor involved. A great deal of the savings can be due to organizational learning or improvements. It has even been proposed that a more correct name for this theory would be "improvement curve". But learning curve has been used successfully for many years and there appears to be no need to add confusion by a name change. It also seems that when more automation is involved in the production, less improvement is expected.

Uninterrupted production of the same item, using the same processes, will allow the smoothest type of pattern. When interruptions occur, we have the difficult job of trying to determine how our learning disappears over time. Addressing and quantifying expected perturbations of the curve due to breaks in production is one of the most difficult problems in learning curve analysis. Some items (such as production lines and soft tooling) disappear more quickly than others (such as special facilites and hard tooling). In general, the approach is to address these separate components "unlearning" rates, and use the composite to go back up the learning curve. For example, a six month break in production after 200 units had been produced could result in unit 201 having an expected cost equal to what unit 150 cost. The break would have cost you learning equivalent to the last quarter of your prior production run.

Production of complex items seems to be a prerequisite if you expect a learning pattern to continue. Complex items imply that there are many opportunities for the worker and the organization to learn or improve. There is doubtlessly learning at the beginning of production on non complex items, but we would not expect it to continue for long. Indeed, the production of only a few complex items may not be sufficient for a learning curve pattern. For example, ships are very complex items but many analysts feel that the numbers now produced are so small that no learning pattern should usually be expected.

Major changes either in the item being produced, or in the production process, will also perturb the pattern. Changes in the product can be considered as either deletions, additions, or substitutions. Since a substitution can be considered a simultaneous addition and deletion, it is sufficient to sketch how those two affect the curve. A deletion occurs when a portion of the item being produced will no longer be included. This means that the cost will drop by the percentage of the work deleted. I.e., if the deleted item was 5% of the workload, the learning curve will drop 5% and continue the pattern.

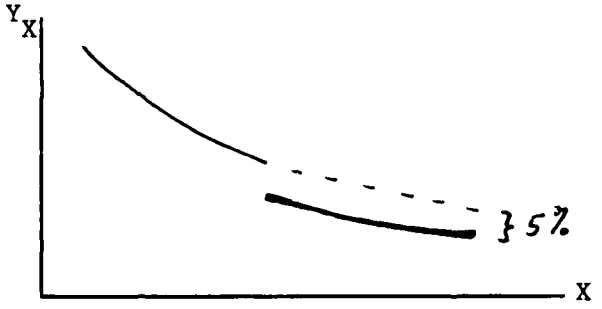


FIGURE 1: DELETION

If on the other hand we have an addition to the item, we are adding something to it. The added item will be produced and will have its own learning curve pattern. These two should not be forced into one curve, they should be kept separate because the unit numbers are different. They are on different portions of the curve.

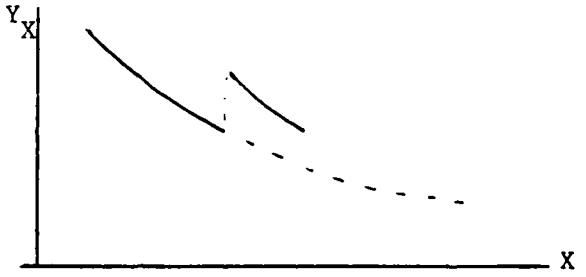


FIGURE 2: ADDITION

Treatment of technological changes in learning curve analysis would depend upon what kind of changes were made. A typical change might be more automation in the production process. This would be expected to lower the cost per unit but would also probably reduce the chances for future improvements and thereby decrease the "slope" of the curve.

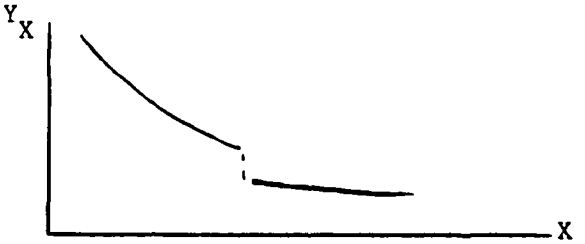


FIGURE 3: AUTOMATION

The last condition is that we need continuous pressure to improve. It is almost a given that lack of pressure will result in lack of improvement. If pressure is maintained for a period of time and then stopped, learning would be expected to stop.

Now is those are some of the expected conditions for a learning curve pattern, what are some of the causes of the decreases?

TABLE 2: Some Causes for the Learning Pattern

- Direct Worker Learning
- Associated Workers Learning
- Management

Many studies and experiments, as well as our own personal experiences, indicate that the individual is able to perform tasks better and/or faster with repetition. The same is true of those workers who perform labor on production of the item. A certain portion of the learning must therefore be attributed to direct workers. In addition, other workers perform tasks that aid the direct worker. As the line continues, those associated workers develop better procedures to assist. For example, the necessary tools may be specifically set aside and more appropriate or better sized tools bought. They contribute to the pattern. And of course, management learns. Lines may be adjusted, more economic quantities or efficient sizes of materials procured. So management also gets some of the credit.

So, now that some conditions and reasons have been discussed, what about some of the forms? The first form usually discussed is called the unit or Boeing formulation. For this form the power function

$Y_X = AX^B$ is appropriate. Where: X is the unit number

Y_X is the cost of unit X

A is the cost of unit one

B is a number that varies with the rate of learning

In this case, the cost per unit is expected to decrease in a regular pattern matching the above equation. This form implies a rapid drop in costs during the first few units and then slower decreases as production continues. The normal way to discuss this learning is to define the learning rate as the percentage of cost decrease between doubled quantities. For example, if unit 4 required 100 labor hours and unit 8 required 80 labor hours, there was a "learning" of 20 hours or a "learning rate" of 20/100 = .2 or 20%. Another even more commonly used term is the slope of the learning curve where:

Slope = 1- learning rate

or

Slope (%) = 100 - learning rate (%)

We can quickly see that the slope is also equal to:

$$\text{Slope} = \frac{Y_{2x}}{Y_x} \quad \text{or} \quad \text{Slope (\%)} = \frac{Y_{2x}}{Y_x} * 100$$

and just for fun we can substitute into this equation and solve for B

$$\text{Slope} = \frac{Y_{2x}}{Y_x} = \frac{A(2X)^B}{AX^B} = 2^B$$

and taking logrithms yields

$$\log \text{ slope} = B \log 2 \quad \text{so } B = \frac{\log \text{ Slope}}{\log 2}$$

where the slope is in decimal form.

There are normally constraints on the slope and on B. A slope of 100% means the learning rate is zero and is the least we should expect. That makes a good upper bound and would have a B value of zero. On the other hand, the maximum (practical) learning rate seems to be 50% or a slope of 50%. This equates to a B of -1. There are no great secrets about the mechanics of the unit formulation.

It is the first formulation introduced in most courses although most consider it to be the second formulation developed. The credit for its development goes to J. R. Crawford who was associated with the Stanford Research Institute and the Air Materiel Command after World War II. Early work on patterns in certain direct costs had been done by Col Leslie McDill at McCook field in Dayton. A contract using learning curves (probably the unit formulation) was awarded to Boeing in 1925 for the P-12E.

The cumulative average formulation was originally presented by T. P. Wright in his 1936 article on "Factors Affecting the Cost of Airplanes". At any rate, Wright states that his work with learning curves began in 1922, so there are 14 years of development that are relatively undocumented. The formulation can be stated as:

$$\bar{Y}_x = AX^B$$

where X is the unit number

$\bar{Y}_x$ is the average cost of units 1 through X

A is the cost of unit one

B is a small negative number related to the rate of learning

Here the cumulative average cost decreases in the same pattern as the unit costs did in the unit form. The slope in this form is defined as:

$$\text{Slope} = \frac{\bar{Y}_{2x}}{\bar{Y}_x}$$

If we fix the slope and A, this formulation assumes more learning during the first units than did the Boeing (unit) formulation. This can be quickly verified by recognizing that for an 80% slope and A value of 1000, the following unit costs apply.

Unit #	Unit Costs - 80% Boeing	Unit Costs - 80% Cum Avg
1	1000	1000
2	800	600
3		

In their theoretical form above, both unit and cumulative average formulations have a smooth pattern that never changes. Learning goes on so long as units are produced. Their primary difference is at the start of the production. Reasons given for this difference have to do with the management of the company and the amount of work done before the beginning of production. Companies that do a lot of prior planning and work to get manufacturing problems resolved would more probably experience the unit pattern. Companies that buy time and address these problems during production would be more likely to experience a cumulative average pattern. Does use of one pattern versus another indicate good or bad management? Of course not. In some cases, the uncertainty inherent in the situation would lead good managers to postpone solution of the manufacturing problems.

Logrithmic Transformations.

One handy feature of the power function form of learning curve patterns is that the relationship is linear when transformed to logrithms. So,

$$Y_x = AX^B \text{ and } \log Y_x = \log A + B \log X$$

are equivalent. Since most analysts prefer not to work in logs, the use of log-log graph paper is standard in learning curve application. Plotting the costs against the unit number on log-log paper is the same as plotting the log of the cost against the log of the unit number on regular (arithmetic) graph paper. This linear charteristic makes costs very easy to project. Most of us, with even limited artistic ability, can (with the help of a straight edge) draw a straight line and read a number off a scale.

The only remaining problem in the application of either formulation is to somehow adjust what is often lot data to a form we can use on the graph. If a lot of ten units (say units 31-40) required 20,000 labor hours, what should be plotted? For the unit formulation, we should plot average unit cost at the average unit. For other than the first lot we always plot the lot average cost at the lot mid point (middle unit number). If plotting the unit formulation we would thus plot the value 2000 at unit number 35. For the first lot we typically use a rule of thumb to help find a better "average unit" than the mid point. The rapid decrease during the first few units causes the lots middle unit to no longer be average. Costs to the left would overbalance costs to the right, so we say that if lot one has ten or more units, $n/_3$ is more appropriate to use as a lot mid point for our graph.

Now, if we wanted to plot for the cumulative average formulation, we should plot the cumulative average values. That means we need a running total of costs and total units produced after each lot. We will then plot the cumulative average cost against the last unit of the last lot.

Analyzing the Graph

Now that the lot data is reduced to a graph, what should we do with it? As always, a graph helps us visualize the situation that may be hidden in the data. The graph may allow us to decide which pattern appears to fit this case. It may illustrate additions and deletions. One thing it definitely will do is lead toward questions. For example, an unusual decrease between lots 4 and 5 might indicate some sort of deletion. The graph will not provide the answer, but its analysis will provide the question.

Slope Changes

Most people recognize that production situations can be very complex. There are many different companies, managers, products, and constraints. It is unlikely that any one or two formulations would apply in every production case. This has proved true in learning curve analysis also with many well thought out and logical alternatives.

One alternative is the variable slope or S-Curve proposed by Cochran. His understanding of the production situation is that during the first few units there is very little, if any, push for cost reduction. At that point in time the company is exploring the different ways the tasks can be performed. Once this exploration ceases and the company decides on how to proceed, they press for cost reduction until they have a mature line. Once mature, with costs that are reasonable, the companies pressure to improve diminishes. This approach could lead to use of a 90% curve for units 1-5, a 75% curve for units six through seventy, and a 85% curve for units 70 on. One interesting item on this form is that the pressure to improve continues longer for a larger buy.

Another form recently introduced says that unit costs depend upon two factors, unit number and production rate. The theory is that faster production rates will promote faster learning and that the form of the relationship is:

$$Y_x = AX^B R^C$$

where R is the production rate and C is a small negative number. This was first published by Larry Smith in a Doctoral Dissertation form the University of Oregon. While the logic is impeccable, and in some cases the production rate does significantly contribute to the ability to project costs, in other cases it does not. This may be due to the inability to purify the data bases used (i.e., adjust for all changes such as additions and deletions) or problems with accounting systems. It may also be the case that the production rate changes in the data base were too small to have much effect.

The End of Learning

As has been stated, if pressure to improve ceases, improvement ceases. It is thus important to decide when and if we expect learning to cease. A company that expects learning to continue through unit 200 will probably press up until that time. A European manufacturer at the National Estimating Society's Conference '82 indicated that their analysts had expected learning to cease at a certain point, but that it continued at least so long as there was a reasonable production rate. World War II references indicate the patterns continued. It thus seems that there is no magic unit number for such a stop in learning. Some companies will indicate that they experience learning until they achieve standards. This is doubtlessly true, but probably reflects more on the diminished pressure than on any flaw in the theory.

One thing that may be expected near the end of a production effort, regardless of the unit numbers, is called toe-up. As a line winds down, you experience personnel turbulence both in production and management. This would result in some cost increases.

CONCLUSION

All in all, learning curve theory fills the bill for a logical pattern. Each of the patterns discussed makes sense and has been used in cost analysis. The choice of which formulation applies depends upon what is expected in the particular case being worked. The solution to better learning curve analyses is not to simplify the options, but to better recognize the implications and appropriateness of each.



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METHODS AND PROBLEMS IN MEASURING PRICE LEVEL CHANGES

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METHODS AND PROBLEMS IN MEASURING PRICE LEVEL CHANGES

INTRODUCTION

This paper addresses a topic which is very familiar to cost analysts--the importance of a price index in normalizing cost data for price level changes. The issues at hand however, are not the necessary application of a price index, but rather, (1) the methods used in developing a historical index and (2) distortions which may result by applying one index as opposed to another.

Most attempts to construct price indices have relied on the input method of pricing. This approach resembles the way they used to weigh hogs in Texas. They would get a long plank, put it over a crossbar and somehow tie the hog on one end of the plank. Then they would search around until they found a stone that would balance the weight of the hog. Then they would try and guess the weight of the stone. A great deal of the input method of pricing seems to be analogous to the way they used to weigh hogs in Texas. The input approach measures factor input price changes weighted in fixed proportions to estimate the industry output price change. In other words, labor, material and in some cases overhead and profit price variations are used to estimate the price change of a completed product such as an aircraft or ship. The input method of pricing has two major drawbacks: (1) complications in accounting for output quality changes and (2) any variations in productivity are extremely difficult to measure and incorporate into the estimate of price change.

In industries where the output is clearly defined (for example the steel industry) the output method of pricing is typically employed. Rather than measure the price change of factor inputs, one measures the price change of the output directly. In the steel industry, the output may be a ton of similiar grade steel. The output is easy to define and has remained similar in quality for many years.

The output method of pricing is preferable since changes in productivity, the mix of labor and material, cost of capital and profit are indirectly incorporated in the index. The output method of pricing has generally not been employed in the shipbuilding industry, for example, for two major reasons:

1. The quality of the output has been continually changing. Ships today are different than ships built in the past in terms of equipment and technical performance characteristics.

2. Many engineering changes are made on any given ship. Thus, even two ships of the same class, constructed consecutively, can be different by the time the second ship is commissioned.

Section I of the paper discusses a few of the problems which may be encountered due to an index based on input price variations. Among these problems is the difficulty in normalizing for substitution among factor inputs. For example, the Merchant Marine Act of 1970 stimulated shipyard modernization. 1/ This increase in capital goods should, in theory, reduce the labor content on ships. This implies the fixed weightings of factor input price variations may have changed over time. Also addressed in Section I is a theoretical approach, at an aggregate level, of developing an index based on the output method of pricing while holding output constant.

Section II discusses distortions which may result in cost analysis due to the selection of one particular index over another. Topics include the influence an index may have on CER development and total factor productivity trends.

The shipbuilding industry and to a lesser extent the aircraft industry, are used as examples throughout the paper. Many of the ideas presented could equally apply to other industries. The shipbuilding industry

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1/ Relative Cost of Shipbuilding, Dept. of Commerce, October 1979, pg. 5.

is emphasized because of our recent work for Naval Material Command and the long history between shipbuilders and price indices. In fact, the Consumer Price Index (CPI) was born and first used by the government to adjust the wages of shipbuilders during the World War I inflation. 1/

I. METHODS IN DEVELOPING INDICES

Most attempts to construct prices for ship and aircraft construction in the past have relied on the input method of pricing. Since the ouput is very difficult to price, the material and labor inputs are used to develop estimates of the output price change. An example of this type of index is the Bureau of Labor Statistics (BLS) Shipbuilding Index. The index is based on a 50/50 weighting of labor and material price changes. The index is only used for contract escalation purposes and may not be representative of historical price changes. Our concern is simply to illustrate the method of developing an index based on factor inputs. The material portion of the BLS index is based on three Producer Price Indices (PPI) and weighted as follows:

45% Iron and Steel
40% General Purpose Machinery and Equipment
15% Electrical Machinery and Equipment

The labor portion of the index is based on straight-time average hourly earnings for shipyards selected by Naval Sea Systems Command. Other indices are also constructed using this approach, most notably, the Consumer Price Index (CPI). Analysts familiar with DoD are aware that there are many indices available which may be appropriate for normalizing historical cost data. In terms of the aircraft industry there are several indices available. Generally, aircraft indices are developed as a composite of

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1/ "Our Flawed Inflation Indexes," Edward Meadows, Fortune, April 24, 1978, p. 67.

three indices, one for airframe, one for engines and one for avionics. Each of these subindices, are then weighted by a factor which reflects the percentage of aircraft cost changes which are attributable to, for example, engine cost changes. The weightings used in particular Air Force [1/] and Army [2/] indices are tabulated below:

	% OF AIRCRAFT COST	
SUBINDEX	USAF	USA
Airframe	60	70
Engine	20	20
Avionics	20	10
	100%	100%

Each of the subindexes are then weighted between labor and material. The weightings for the engine index for the same Air Force and Army indices are:

	% OF ENGINES COST	
	USAF	USA
Labor	65	47
Raw Materials	35	53
	100%	100%

The raw material portion of each subindex are comprised of several PPI and the labor portion are based on Employment and Earnings data for selected industries by SIC code. For example, the PPI for aluminum represents 7.1 percent in the engine subindex for the Army and two percent for the Air Force. Whether any of these weightings are truly representative is not the concern of this paper. The point is to simply illustrate the method of input pricing and to point out its relatively wide acceptance among cost analysts.

1/ "Generic Inflation Indexes for Weapon Systems," AFSC CAIG Research Report NR1, Allen Fatkin, HQ AFSC/ACCE, July 1981, p. 4.

2/ "Historical Inflation Program," U.S. Army Troop Support and Aviation Material Readiness Command, Technical Report 82-2, Warren Gille, Jr., March 1982, p. 23.

From the foregoing discussion it should be obvious there are three essential ingredients to any index based on the pricing of inputs: (1) knowledge of what inputs are required in the production of the output, (2) the weightings or share of each component making up the composite index, and (3) information concerning the price change between time periods for each component of the composite index. However, before discussing each of these ingredients a cursory review of the OSD indices for Naval procurement appropriations is provided.

The Office of Secretary of Defense, Comptroller, approves four Naval procurement indices. The four procurement appropriations for the Navy are aircraft procurement (APN), weapon procurement (WPN), other procurement (OPN), and shipbuilding and conversion (SCN). The four indices, along with others, are periodically published by the Chief of Naval Operations, Systems Analysis Division (OP-96D). Exhibit 1 displays the four indices with base year equal to mid-fiscal year 1981 over the time period FY65-FY81.

Apparent from Exhibit 1 is the APN, WPN and OPN indices are exactly the same. This occurs since all four of the procurement indices reflect the actual change in one index, the Federal Purchases Deflator for Defense. The SCN index appears to be the only one of the four which has been adjusted to perhaps more accurately reflect historical shipbuilding price changes.

Surely, the aircraft industry has experienced different price variations than the weapon construction industry and both in turn different from other Naval procurements. The point is that all of these indices leave much to be desired and all cost analysts should be concerned about applying these indices when normalyzing historical cost data. 1/

The following subsections return to the discussion of the three necessary ingredients to any index based on the pricing of inputs.

1/ New historical inflation indices have been promulgated. These have not been included in this discussion.

EXHIBIT 1

NAVAL PROCUREMENT INDICES */
Base Year: Mid-FY81

FISCAL YEAR	APN	WPN	OPN	SCN
1965	39.67	39.67	39.67	22.28
66	40.99	40.99	40.99	23.55
67	42.45	42.45	42.45	25.10
68	43.90	43.90	43.90	26.86
69	45.29	45.29	45.29	29.90
70	47.07	47.07	47.07	32.34
71	49.21	49.21	49.21	35.25
72	51.09	51.09	51.09	37.83
73	53.21	53.21	53.21	40.59
74	56.28	56.28	56.28	46.88
75	61.24	61.24	61.24	54.52
76	65.28	65.28	65.28	63.08
77	67.60	67.60	67.60	64.41
7T	70.16	70.16	70.16	68.19
78	74.93	74.93	74.93	73.92
79	81.46	81.46	81.46	81.17
80	89.37	89.37	89.37	89.37
81	100.00	100.00	100.00	100.00

*/ "Escalation Indices and Outlay Profile Factors," Chief of Naval Operations, Systems Analysis Division (OP-96D), Resource Analysis Group, May 1982.

A. What Are The Inputs?

There are three categories of basic inputs to the production of a good or service: labor, capital and environment. Materials are simply a portion of the capital required in the production process. Costs which cannot be segregated as direct cost related to specific contracts such as environmental and non-material capital costs are pro-rated to overall company operations as overhead. Normally, overhead costs include a substantial amount of labor costs and labor related costs as well as taxes, depreciation, plant maintenance, modernization and repairs, utility costs, selling expense and numerous costs of lesser consequence. Thus, every index based on input pricing should include an overhead component along with direct labor and material price changes. Many price indices available within DoD do include overhead components. Two such indices are the one developed by Naval Air Systems Command [1/] and Naval Sea Systems Command. [2/]

The difficulty with overhead costs is the method of assigning these costs to specific company operations. Overhead costs may be considered to have fixed and variable portions in the short run. Variable overhead costs may be the indirect labor while fixed overhead costs are items such as depreciation, and other expenses which do not fluctuate with business volume. Recognizing the impact business volume may have on overhead rates, it may be desirable to normalize overhead costs by an index of plant utilization or capacity.

B. Weighting Of Factor Input Prices

The weighting factor reflects the portion of output price change which is attributable to a particular input price change. For example,

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1/ "Aircraft Escalation Index," Tom Gilbride, NAVAIR 5243.

2/ "NAVSEA Ship Price Index," SEA017. Note this index only includes overhead price changes for selected years.

labor costs may comprise 50 percent of the cost of a ship. Note, it is necessary to know the cost of the output in order to calculate the weighting factor for each input. In general the cost of the output and all inputs are known for at least one time period, referred to as the base period of the index. The weightings are then calculated for the base period. However, the goal is to know the price change of that particular well defined output if produced in a different time period. This requires recalculating of weighting factors which in turn requires knowing the output price in the second time period. It appears logical to simply calculate the price change of the output produced in the two time periods. The output pricing method is usually not used in the shipbuilding industry for at least the following two reasons:

1. The quality of the output has been continually changing. Ships or aircraft today are different than these systems built in the past in terms of equipment and performance characteristics.

2. Many engineering changes are made on any given ship. Thus, even two ships of the same class constructed consecutively can be different by the time the second ship is commissioned.

Resulting from these and other reasons it is assumed that the weighting factors determined in the base period are applicable in the second time period and usually it is assumed that these weights are appropriate over the whole time range of the index. Therefore, the weighting factors become fixed which assumes no substitution among factor inputs and output quality is held constant over the range of the index.

The issue then becomes a matter of determining the effect of not allowing for input substitution and quality changes. The following quotation is offered concerning the consumer price index calculated from a fixed market basket. "A dollar cost rise of two-to-four percent over one

year for that rigid consumption combination could occur even though the nominal dollar cost of living did not change after allowing for substitution possibilities and quality changes." [1] If two percent a year is considered a reasonable margin of error in the shipbuilding industry after allowing for input substitution and quality change, then a ship built in 1962 inflated to 1982 dollar levels could be over inflated by 49 percent (1.02^{20}). Certainly the possible error from ignoring factor substitution and quality change may be substantial.

Consider the following comments regarding factor substitution in the shipbuilding industry:

> The Merchant Marine Act of 1970 shifted the accent of U.S. shipyards' investments from replacement to modernization and expansion and recently there has been an expansion of ship repair and conversion facilities. Since enactment of the 1970 Act, the shipbuilding industry has invested approximately $1.7 billion for facility modernization and improvements, such as new building basins, new floating drydocks, cranes of unprecedented lifting capacity, plus the introduction of automated equipment and highly mechanized production systems. By these investments, the industry has increased both its capacity and its capabilities. [2]

> Capital can very effectively substitute for labor if the work is sufficiently repetitive in nature or can be engineered to become repetitive. An example of the later is the design practice followed in the highly automated Panel Shop at General Dynamics' Quincy operation. [3]

1/ Exchange and Production: Competition, Coordination and Control, Armen Alchian, William Allen, Wadsworth Publishing Co., 1977, p. 484.

2/ Relative Cost of Shipbuilding, Dept. of Commerce, Maritime Administration, October 1980, p. 5.

3/ "U.S. Shipbuilding: The Seventies in Retrospect-The Prospects for the Eighties," Naval Engineers Journal, Capt. J. R. Fisher, CDR Philip Coady, August 1980, p. 29.

The point is there certainly has been, at least, a partial substitution of capital for less labor in the shipbuilding industry. The effect of the substitution concerning price indexes and overhead rates in particular is unclear. However, the problem should be recognized when applying or developing price indices based on fixed weights of factor input price changes.

C. Prices Of Factor Inputs

As mentioned earlier, prices of factor inputs are typically measured using PPIs and labor price variations are measured by BLS Employment and Earnings data. Consider for a moment what any particular producer price index (PPI) measures. PPI measure average changes in price received in primary markets of the United States by producers of those commodities. The price reflects the market determined value of the particular commodity at a point in time. For example the producer price index for electrical machinery and equipment reflects all factors which affect price, such as, technological improvements, productivity changes, prices of substitute goods, prices of materials, and other supply and demand considerations. The input method of pricing requires that one assume that the factors affecting input price changes also affect output price change. This may not necessarily hold. For example, there have been relatively large technological advances in the electronics industry. By including this PPI into a composite output index requires the assumption that the technological advances made in the electronic industry are applicable to the shipbuilding industry, for example, multiplied by some fixed factor. Further, producer price indices reflect productivity changes in input markets, not the output market. There may have been productivity advances in the electronics industry over the past decade. However, the productivity of integrating the electronics equipment into the respective weapon system may not have changed. The productivity changes reflected in the input industry PPI will only by accident reflect productivity variations in the output industry.

The BLS Employment and Earnings data measure the straight time average wage rate for labor in the output industry as reflected by SIC codes. An increase in wage rates may to some extent indicate labor productivity advances. By using the BLS labor cost indices with fixed weights, allowance is being made for labor productivity changes, only to the extent that wage changes match labor productivity changes.

Recall that the input method of pricing is used to estimate the price change of the output. Certainly, if one could measure the output price change directly, this approach would be preferable. The output method of pricing is discussed in the following section.

D. Output Pricing

The output method of pricing, while theoretically preferable, has generally not been used primarily as a result of quality changes in the output. Other difficulties with this approach, particularily with ships, concerns the amount of time required to construct a ship. For some ships, especially lead ships, the construction period may be several years. Thus, it is extremely difficult to measure the value of the output on a yearly basis.

One approach to avoid these problems is to re-price a "frozen design" every year. This is the approach used by the Bureau of Economic Analysis when calculating price changes of military ships. 1/ Ship designs were held constant and the changes in labor hours, labor rates, materials and overhead necessary for producing identical ships in succeeding time periods were estimated. Since designs were identical in two time periods, the aggregation of the second set of costs compared to those of the base period yield the change in price for the identical amount of ship construction in the second period. The frozen ship approach has few theoretical problems. Inputs are specifically related to a defined output

1/ Price Changes of Defense Purchases of the United States, Dept. of Commerce, Bureau of Economic Analysis, March 1979.

and current period price changes were reflected in the output price deflator. The method reflects price effects of changes in production implicitly. Since the inputs to produce the identical output were measured over time, input mix changes due to productivity, labor/capital substitutions, or any other cause were reflected in the mix of inputs priced and, therefore, in the output price that was estimated.

The frozen ship approach eliminates, by definition, quality changes in the output. Since engineering and design changes do occur in ship construction, this renders the "frozen" ship design obsolete. The Bureau of Economic Analysis estimates that a frozen design should be replaced every five years. A new design must then be selected and an overlap period priced for both ships to provide a link period for the new design. It appears that the frozen design approach may be the solution to a very difficult pricing problem.

From a practical standpoint, the frozen ship approach requires that shipyards re-price the frozen designs every year. This may be analogous to the fox watching the hen house. Further, it is unclear whether the shipyards expend the resources to adequately re-price the designs each year.

This section has served to illustrate the variety of techniques which may be utilized in developing a historical price index for a particular weapon system. Not surprisingly, there are a variety of indices which are publicly available in order to normalize a historical cost data base for price level changes. The following section discusses distortions which may occur due to the selection of one index over another.

II. THE INFLUENCE OF PRICE INDICES ON HISTORICAL COST TRENDS

Any analysis of historical cost trends is highly dependent on the selection of a price index to normalize historical costs. For example, to compare a ship built in 1960 with one built in 1980 requires inflating the 1960 ship to 1980 price levels. The higher the inflation over the time period, the higher the 1960 ship becomes in constant dollars, relative to 1980. Consider a 1960 ship costing $10,000 per ton and a 1980

ship costing $25,000 per ton both in current ("then-year") dollars. If the price level only doubles in the 20 years, then the 1960 ship costs $20,000 per ton in 1980 constant dollars. But, if inflation triples, then the 1960 ship costs $30,000 per ton, or more than the 1980 ship. Thus, ship costs per ton may be increasing or decreasing depending on the selection of a price index.

The first subsection below calculates total factor productivity trends for the shipbuilding industry using different indices to adjust the industry output prices. The second subsection discusses distortions which may occur in CER development as influenced by the price index selection.

A. The Influence of Different Price Indexes on Productivity Measures

Productivity is a measure of comparison between what is produced and the quantity of resources employed in production. In an industrial process, output is sales, units, or a physical property such as weight. Inputs are classified as labor, materials and capital (plant and equipment). When productivity increases, fewer inputs are required to produce a given amount of output. Consequently, enhanced productivity results in lower real costs, increased rewards or returns to productive resource inputs, or some combination of these two effects. A corollary is that reduced productivity leads to higher output costs, reduced real rewards for inputs, or some combination of these effects. If productivity gains fail to match increases in input resource costs, higher unit costs result. Thus, wage increases without concomitant increases in worker productivity are inflationary.

The way productivity is measured determines the meaning that it carries. Productivity can be any output measure divided by any single input measure or some combined measure of input resources. Traditional discussions of productivity focus on real output per man-hour as for example in the well known series prepared by the BLS. The Bureau of Labor Statistics computes its series for output per man-hour for the private sector as the ratio of gross domestic product originating in the private

sectors to the corresponding hours of all persons employed. The output figures are deflated to constant dollars by adjusting them with price indices.

A more inclusive index of productivity change is "total factor productivity" calculated as the relationship of output to a weighted combination of quantities of different factor inputs used. This measure is preferred to more simple output per man-hour measures since in principle it captures the effects of all factors of production. By way of illustration, output per man-hour may display growth because substantial capital investment per man-hour has occurred. However, total factor productivity may at the same time decline or fail to grow as rapidly as output per man-hour as the productivity of capital declines. Total factor productivity is more difficult to measure in practice since it requires computation of capital services employed.

The method used here is to compute total factor productivity from the well known Cobb-Douglas production function:

$$(1) \qquad Q = PL^{a} K^{1-a}$$

where:

Q = output
L = labor input
K = capital input
P = measure of total factor productivity
a, (1-a) = labor and capital shares of output

Dividing the production function by L yields:

$$Q/_{L} = \frac{PK^{a} L^{1-a}}{L} = P\left(\frac{K}{L}\right)^{a}$$

Differentiating gives:

$$d\left(Q/_{L}\right) = aP\left(\frac{K}{L}\right)^{a-1} d\left(\frac{K}{L}\right) + \left(\frac{K}{L}\right)^{a} dP$$

And dividing by $\frac{Q}{L}$ gives:

$$\frac{d(Q/L)}{(Q/L)} = a \frac{d(\frac{K}{L})}{(\frac{K}{L})} + \frac{dP}{P}$$

Hence, the change in total factor productivity $(\frac{dP}{P})$ is:

$$\frac{dP}{P} = \frac{d(Q/L)}{(Q/L)} - a \frac{d(\frac{K}{L})}{(\frac{K}{L})}$$

or

$$(2) \qquad P^* = (Q/L)^* - a(\frac{K}{L})^*$$

Where * indicates percentage change.

This formula states that the extent of total (factor) productivity growth is the difference between growth in real output per worker and the contribution due to more capital per worker. As a limiting case, it states that if no additional capital per worker occurred, total productivity growth coincides with the growth in output per worker. The more popular but more simple measure of productivity change (output per unit of labor) ignores the right hand term of the equation, the effect of substitution among factor inputs.

We have prepared separate estimates of labor and total factor productivity growth for the U.S. shipbuilding and repairing industry (SIC 3731). Exhibit 2 presents trends in labor productivity, assets per unit of labor and following equation (2) above, total factor productivity trends. All data used to calculate these trends are publicly available through the Department of Commerce, Census of Manufactures.

EXHIBIT 2

PRODUCTIVITY MEASURES */

YEAR	(1) ANNUAL % CHANGE IN VALUE ADDED PER PRODUCTION WORKER HOUR (CIA)	(2) ANNUAL % CHANGE IN VALUE ADDED PER PRODUCTION WORKER HOUR (NAVSEA)	(3) CHANGE IN DE-FLATED FIXED ASSETS ADJUSTED FOR CAPACITY PER PRODUCTION WORKER HOUR	(4) CAPITAL COEFFICIENT IN VALUE ADDED	(5) ANNUAL % CHANGE IN TOTAL FACTOR PRODUCTIVITY (CIA) (1)-((3)*(4))	(5) ANNUAL % CHANGE IN TOTAL FACTOR PRODUCTIVITY (NAVSEA) (2)-((3)*(4))
1967						
68	- 8.98%	-13.07%	+ 5.11%	16%	-9.98%	-13.89%
69	+ 1.17	- 3.03	+ 4.74	17	+ 0.36	- 3.83
70	+15.67	+ 9.94	+ 8.09	28	+13.40	+ 7.67
71	- 3.66	- 9.69	+14.40	26	- 7.40	-13.43
72	+ 1.89	- 0.18	+ 9.59	25	- 0.51	- 2.58
73	+10.78	+ 7.10	+ 2.22	30	+10.11	+ 6.434
74	- 0.67	- 0.20	-11.21	31	+ 2.81	+ 3.275
75	- 1.01	- 1.41	- 1.86	32	- 0.41	- 0.81
76	+ 2.66	- 2.28	+17.03	33	- 2.96	- 7.90
77	+ 2.75	- 0.09	- 9.91	35	+ 6.22	+ 3.38
78	+ 2.59	+ 2.67	- 3.22	36	+ 3.75	+ 3.83

*/ All data backup is available in the Appendix.

Referring to Exhibit 2, two trends of labor productivity are displayed under two assumptions. The first column reports the annual percent change in output per production worker hour where output is deflated using the NAVSEA Ship Price Index available through NAVSEA 017. The second column displays the annual percent change in output per production worker hour, but output is deflated using a shipbuilding index prepared by the CIA Military Economic Branch. Both indices are shown in the Appendix. The measure of output is value added by the shipbuilding and repair industry (SIC 3731).

The third column in Exhibit 2 displays the annual percentage change in capital per production worker hour. This ratio allows insight into the degree of substitution of capital for labor in the shipbuilding industry. Capital is measured using Census data on value of fixed assets for SIC 3731. Value of fixed assets has been deflated to constant dollars using the BLS capital equipment deflator. Fixed assets were further adjusted by a capacity utilization index for the transportation sector of the economy (SIC 37). In effect this last adjustment reflects the overall business cycle in the transportation industry. This last adjustment is necessary since a measure of capital employed in the production process is preferable to a measure of the capital on hand in the industry. If one believes there was excess capacity in the shipbuilding industry relative to the transportation sector as a whole, then total factor productivity is understated in this report. The fourth column in Exhibit 2 presents the capital share coefficient for capital in value added. This coefficient is calculated as:

$$1 - \left(\frac{\text{Payroll}}{\text{Value Added}}\right)$$

The final column reports total factor productivity annual percentage change under the two assumptions: (1) output deflated using the "CIA Index" and (2) output deflated using the "NAVSEA Ship Price Index".

Exhibit 3 develops two total factor productivity indices based on the information provided in Column 5 of Exhibit 2. Finally, Exhibit 4 is a graphical display of the two productivity indices.

Apparent from these Exhibits, particularly Exhibit 4, is the selection of an index is extremely important when examining productivity trends. When output (value added) is deflated with the NAVSEA index, productivity appears to have declined over the time period. When the CIA index is used, productivity is shown to increase. The true direction or magnitude of the productivity trend is irrelevant to this paper. The important factor to note is the selection of an index to adjust historical cost data is critical to the analytical results.

The following section briefly addresses distortions which may occur when normalizing historical costs for price variations in the development of cost estimating relationships (CERs).

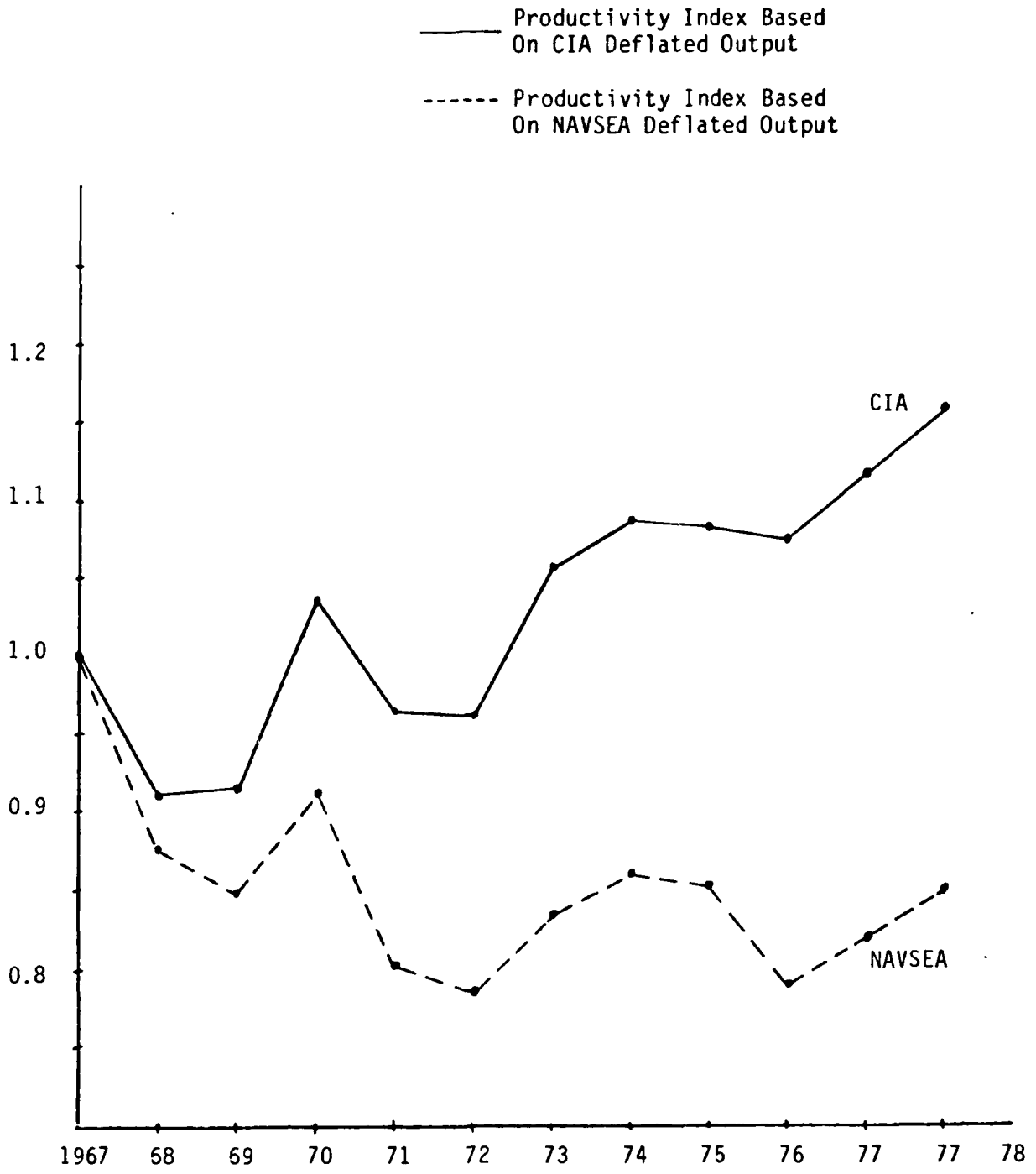
EXHIBIT 3

TOTAL FACTOR PRODUCTIVITY INDICES

YEAR	PRODUCTIVITY INDEX BASED ON CIA DEFLATED OUTPUT	PRODUCTIVITY INDEX BASED ON NAVSEA DEFLATED OUTPUT
1967	1.000	1.000
68	0.911	0.878
69	0.914	0.846
70	1.037	0.911
71	0.965	0.803
72	0.960	0.783
73	1.057	0.833
74	1.087	0.860
75	1.083	0.853
76	1.051	0.791
77	1.117	0.817
78	1.159	0.849

EXHIBIT 4

TOTAL FACTOR PRODUCTIVITY INDICES



B. Inflation Indices and CERs

JWN developed a series of cost estimating relationships (CERs) for ship costs under contract to the Navy. Two different indices were used in normalizing the data base: (1) the then approved SCN index and (2) an index derived by Data Resources, Inc. (DRI) under contract to the Navy. The same explanatory variables were used and CERs were generated for both SCN and DRI adjusted data. CERs in the following format developed for non-nuclear surface combatants will illustrate two problems that result. The form of the CERs was:

$$C = a X^b Y^c$$

where C = Cost, X = light ship weight and Y = shaft horsepower, and a, b, and c are statistically derived parameters.

Two elements of cost were estimated: ship construction cost and total cost less plans cost. Ship construction cost (plus propulsion costs when provided as GFE) represent the price paid to the shipyard. Total cost includes other hardware like weapons and electronics (almost always GFE) and a variety of services provided by various Navy commands and contractors other than the yard. Plans cost, which includes the detailed design of the ship, were excluded and estimated separately.

The CERs based on costs adjusted with the SCN index predicted substantially higher costs than the CERs based on the DRI index. The CERs based on the SCN index estimate 20 percent higher costs for the larger ships in the particular stratification of ships analyzed and 60 percent higher for the smaller ships in the sample. The fact that the SCN-based CERs predicted higher costs than the DRI-based CERs is not surprising. Since the SCN inflation factors are substantially greater than DRI, the normalized costs for each ship in the SCN sample is substantially greater than the cost for the same ship when adjusted by the DRI factors. The difference between small and large ships is surprising since, in general, one would not expect this result from the form of the CER used. It turns out, however, that the smaller weight ships in the sample analyzed were

actually produced earlier in time than the larger ships so that the differences in inflation rates had a more complex effect on the CERs rather than the expected scaler effect. More precisely, the statistically derived parameter b, the exponent on light ship weight, changes significantly; the parameter a which should reflect the scaler effects of the differing indices also changes; and C, the exponent for shaft horsepower is relatively stable. 1/

Thus the index used to normalize historical data can impact on the predictive capability of the resulting CER often in unpredictable ways. The substantial difference between the predicted cost of large and small ships was not readily apparent but is of importance in applying the CERs to derive estimates for new ship programs. There is a second problem which is not as demonstratable but is none the less real. Total ship costs, the second set of CERs developed, include a mix of ship construction, electronics (radar, sonars, fire control systems) and weapons hardware, and engineering services. Can any one index properly reflect price change impacts over time for such a diverse set of activities? Clearly the mix of shipyard work and government furnished equipment such as electronics changes when one considers various missions, yet the SCN index as promulgated is generally applied to all types of ships: submarines, surface combatants, amphibious, auxiliary and others. While the example cited may be an extreme case, it seems clear that improper application of indices to account for inflation in normalizing costs can inhibit the utility of otherwise useful parametric CERs.

1/ Part of the difference in coefficient values results from the high, and perhaps too high, degree of colinearity between light ship weight and horsepower. This aspect of the CERs is not important to the discussion here.

APPENDIX

BACKUP DATA TO PRODUCTIVITY ANALYSIS

SHIPBUILDING AND REPAIRING

SIC 3731

	VALUE ADDED (M$)	PRODUCTION WORKER HOURS (1000)	GROSS VALUE OF FIXED ASSETS (M$)	PAYROLL PERCENT OF VALUE ADDED
1967	1430.4	231.0	689.5	75
68	1345.9	232.6	729.2	84
69	1451.3	235.3	826.6	83
70	1609.8	212.8	948.1	72
71	1575.3	207.9	1021.5	74
72	1881.3	233.4	1227.3	75
73	2216.1	239.0	1297.2	70
74	2547.3	249.5	1531.2	69
75	2923.2	253.9	1808.7	68
76	3287.3	261.6	2156.9	67
77	3825.0	277.2	2090.0	65
78	4106.5	268.4	2138.2	64
79	4586.9	268.1	(NA)	64

SHIPBUILDING

	1/ CIA	2/ NAVSEA	3/ CAPITAL EQUIPMENT DEFLATOR	4/ SHIPS CAPACITY UTILIZATION
1967	100.0	100.00	100.00	84
68	102.66	107.50	103.50	87
69	108.17	118.17	106.9	84
70	114.70	131.83	112.0	75
71	119.25	146.21	116.6	81
72	124.50	155.82	119.5	85
73	129.29	167.37	123.5	87
74	143.31	184.66	141.0	78
75	163.25	211.20	162.5	76
76	173.56	235.89	173.4	82
77	185.49	259.26	184.6	86
78	200.48	279.98	199.2	85
79	218.28	307.41	216.5	80

1/ "Shipbuilding Index," CIA Military Economic Branch, March 19, 1981.

2/ "Ship Price Index," NAVSEA 017.

3/ "Producer Price Index," Capital Equipment, BLS.

4/ "Capacity Utilization Rates (%)," Statistical Abstract of the U.S., Transportation Equipment.

NORMALIZED SHIPBUILDING INDUSTRY DATA

	VALUE ADDED CIA	VALUE ADDED NAVSEA	PRODUCTION WORKER HOURS	VALUE OF FIXED ASSETS
1967	1430.4	1430.4	231.0	579.2
68	1311.0	1252.0	232.6	613.0
69	1341.7	1228.1	235.3	649.5
70	1403.5	1221.1	212.8	634.9
71	1321.0	1077.4	207.9	709.6
72	1511.1	1207.4	233.4	873.0
73	1714.1	1324.1	239.0	913.8
74	1777.5	1379.5	249.5	847.0
75	1790.6	1384.1	253.9	845.9
76	1894.0	1393.6	261.6	1020.0
77	2062.1	1475.4	277.2	973.7
78	2048.3	1466.7	268.4	912.4
79	2101.4	1492.1	268.1	(NA)

METHODS AND PROBLEMS IN

MEASURING PRICE LEVEL CHANGES

WHAT WE WILL COVER:

1. HOW INDICES ARE PREPARED.

2. IMPACTS OF INDICES ON COST ANALYSIS

   - SELECTING AN INDEX
   - IMPACT ON PRODUCTIVITY MEASUREMENT
   - IMPACT ON CER DEVELOPMENT AND USE

DEVELOPING INDICES

- OUTPUT METHOD
  - PRICE CHANGES OF STANDARD PRODUCT
- INPUT METHOD
  - PRICE CHANGES OF LABOR AND MATERIALS CONSUMED IN PRODUCING A PRODUCT

SOME EXAMPLES

BLS - ESCALATION CLAUSES FOR SHIPS

- LABOR 50%
- MATERIALS 50%

IRON AND STEEL	45%
GEN PURPOSE MACHINERY	40%
ELECTRICAL MACHINERY	15%

SOME EXAMPLES

AIRCRAFT

SUBINDEX	PERCENT OF AIRCRAFT	
	USAE	USA
AIRFRAME	60	70
ENGINE	20	20
AVIONICS	20	10

SOME EXAMPLES

ENGINES

	PERCENT OF COST	
	USAF	USA
LABOR	65	47
MATERIALS	35	53
	100	100

OSD GUIDANCE

NAVAL PROCUREMENT INDICES

(1981 = 1.00)

	APN	WPN	OPN	SCN
1965	2.52	2.52	2.52	4.47
1970	2.12	2.12	2.12	3.09
1975	1.63	1.63	1.63	1.83
1981	1.00	1.00	1.00	1.00

SOURCE: OP-96D, MAY 1982

INPUT METHOD

USUAL ASSUMPTIONS

- QUALITY OF OUTPUT CONSTANT
- MIX OF INPUTS CONSTANT

WHAT REALLY HAPPENS

- QUALITY OF OUTPUT IS CHANGING
- MANUFACTURING TECHNOLOGY IS CHANGING
- MATERIALS TECHNOLOGY IS CHANGING

INPUT METHOD

IMPLICATIONS

- CPI CALCULATED FROM A FIXED MARKET BASKET.
- COST RISE OF TWO-TO-FOUR PERCENT EVEN WITH NO INFLATION.
- IF THIS OCCURRED ITEM PURCHASED WITH 1962 DOLLARS COULD BE OVERINFLATED APPLYING CPI TO OBTAIN 1982 DOLLAR PRICE BY $(1.02)^{20} \approx 49$ PERCENT.

PRICES OF FACTOR INPUTS

- MATERIALS - PPIs
- LABOR - BLS EMPLOYMENT AND EARNINGS DATA

BUT

- PPI REFLECTS CHANGES IN PRODUCING INDUSTRY NOT THE DEFENSE INDUSTRY USER.
- BLS WAGE DATES DO NOT NECESSARILY REFLECT LABOR PRODUCTIVITY.

SO

- TRACKING INPUTS DOES NOT REFLECT PRODUCTION PROCESS.

A PRODUCTIVITY EXAMPLE

ASSUMPTION

- COBB - DOUGLAS $Q = PL^{A} K^{1-A}$
- REARRANGE TO $\frac{Q}{L} = \frac{PK^{A} L^{1-A}}{L} = P\left(\frac{K}{L}\right)^{A}$
- DIFFERENTIATE AND REARRANGE

$$\frac{DP}{P} = \frac{D(Q/L)}{Q/L} - A\,\frac{D(K/L)}{K/L}$$

OR

$$P^{*} = (Q/L)^{*} - A(K/L)^{*}$$

APPLICATION

Q = VALUE ADDED

K = FIXED ASSETS ADJUSTED FOR CAPACITY UTILIZATION

L = PRODUCTION WORKERS

P = TOTAL FACTOR PRODUCTIVITY

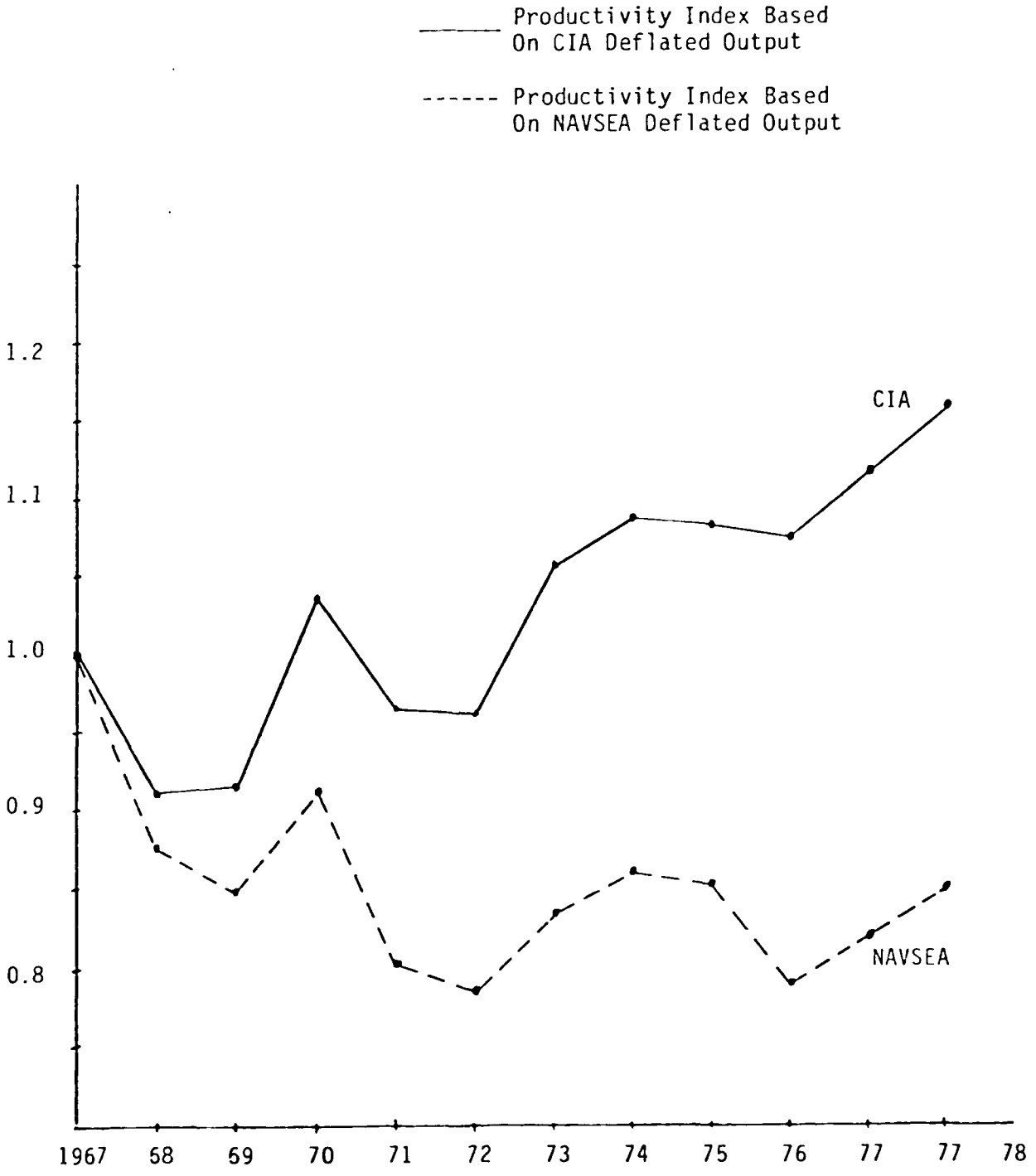
NOTE: DATA ADJUSTED TO CONSTANT DOLLAR BY:

(1) SCN INDEX

(2) CIA INDEX FOR SHIP CONSTRUCTION

EXHIBIT 4

TOTAL FACTOR PRODUCTIVITY INDICES



CER EXAMPLE

- CER FORM COST $= A(WT)^B (HP)^C$
- DATA BASE ADJUSTED USING:

  SCN INDEX

  DRI INDEX DEVELOPED FOR NAVMAT

- EXPECTED RESULTS FROM COMPARING CERs
  - "A" FACTOR WOULD REFLECT SCALAR DIFFERENCES BETWEEN SCN AND DRI INDICES
  - "B" AND "C" COEFFICIENTS RELATIVE STABLE

CER EXAMPLE

RESULTS

- SCN DATA ESTIMATE COMPARED TO DRI DATA ESTIMATE

  SMALL SHIP - SCN = 1.6 (DRI)

  CARGO SHIP - SCN = 1.2 (DRI)

- WHY?

  - SMALL SHIPS PRODUCED EARLIER IN TIME THAN LARGE SHIPS IN SAMPLE ANALYZED.

  - "B" AND "C" COEFFICIENTS CHANGED SUBSTANTIALLY.

CONCLUSION

- COST ESTIMATES NO BETTER THAN THE DATA BASE.
- HISTORICAL DATA MUST BE NORMALIZED.
- SELECTION OF AN INFLATION INDEX CAN IMPACT ON THE ESTIMATING VALIDITY OF CERs IN COMPLEX AND UNPREDICTABLE WAYS.

DATA BASES FOR COST ANALYSIS

NASA's REDSTAR

AD P001233

(REsource Data STorage And Retrieval)
DATA BASE SYSTEM

Presented By
JOHN R. TURNEY
PLANNING RESEARCH CORPORATION
Engineering Cost Analysis Department
Huntsville, Alabama

The 17th Annual DoD Cost Analysis Symposium
Sheraton National Hotel
Arlington, Virginia

12-15 September 1982

prc

WHY ESTABLISH A DATA BASE?

- THERE IS USUALLY NO CENTRAL SOURCE OF DATA
- MANY INDIVIDUALS HAVE THEIR OWN, PRIVATE FILES THAT ARE NOT CENTRALIZED
- A LOT OF INFORMATION IS NOT IN WRITTEN FORM. THE INDIVIDUALS THEMSELVES POSSESS THE DATA IN THEIR HEAD
- MOST ACCOUNTING SYSTEMS CONTAIN THE REQUIRED DATA - IT'S JUST NOT IN THE REQUIRED FORMAT - IT TAKES TIME AND MONEY TO DIG THE INFORMATION OUT
- DATA BASE DEVELOPMENT AND COST RESEARCH ARE USUALLY THE FIRST ITEMS REDUCED OR CUT BACK IN SEVERE BUDGET CUTS, AT A TIME WHEN DATA ARE REQUIRED TO SUPPORT NEW BUSINESS/DEVELOPMENT ACTIVITIES
- MANAGEMENT DECISIONS BIAS THE TYPES, KINDS AND LEVELS OF DATA AVAILABILITY

- PRIOR TO 1970, NASA HAD ACCOMPLISHED THE GOAL OF SENDING MEN TO THE MOON AND RETURNING THEM SAFELY TO EARTH
- PLANNING AND ENGINEERING WAS SET IN MOTION TO DEVELOP A REUSABLE SYSTEM, NAMELY THE **SPACE SHUTTLE**
- COST ESTIMATES WERE REQUIRED IN THE EARLY PLANNING STAGES
- A WEALTH OF DATA WERE REPORTED DURING THE APOLLO PROGRAM - - - HOWEVER;
  - There was no central source of this data (Data being Cost, Technical and Programmatic)
  - These data were not in any uniform format (Mainly by function, and not by program phase, end item or subsystem)
  - Not Normalized
- THUS, THE BEGINNING OF REDSTAR. THE LEAD NASA CENTER IS MSFC (MARSHALL SPACE FLIGHT CENTER) WITH SUPPORT FROM NASA HEADQUARTERS AND THE OTHER CENTERS
- SPECIAL FUNDED STUDIES WERE UNDERTAKEN TO HAVE SOME OF THE KEY HARDWARE DEVELOPERS TO RE-STRUCTURE THEIR HISTORICAL COST DATA

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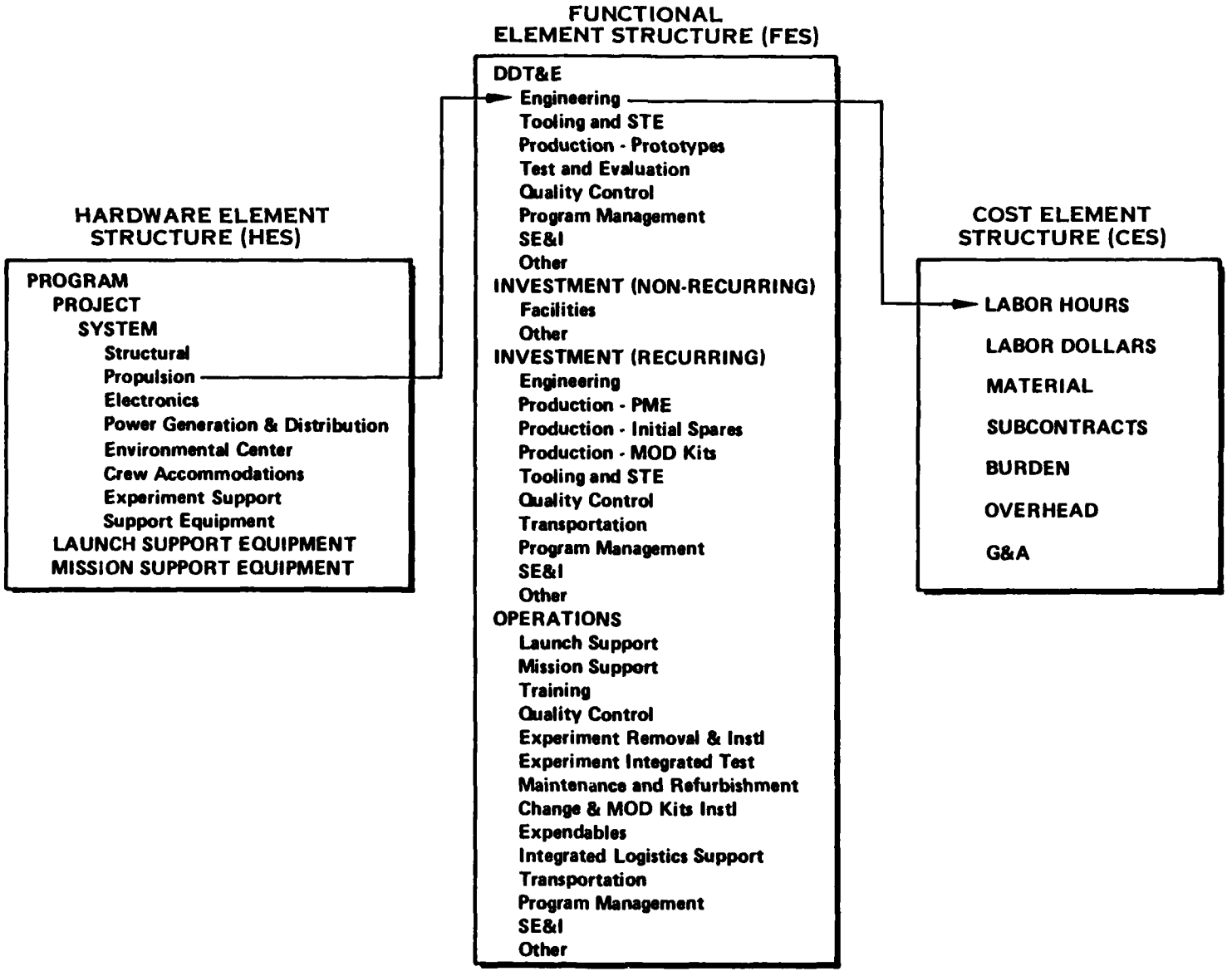
OBJECTIVE OF REDSTAR

TO DEVELOP AN EFFICIENT STORAGE AND RETRIEVAL SYSTEM FOR THE COLLECTION OF HISTORICAL COST, TECHNICAL AND PROGRAMMATIC DATA WHICH ARE UNIFORM AND CONSISTENT, FOR USE IN ESTIMATING AND/OR ANALYZING COSTS OF FUTURE SYSTEMS

- ABILITY TO PROVIDE THE COST ANALYST WITH:
  - Recurring/Non-Recurring Costs
  - To Which End Item
  - What Resource
  - How Resource is Used
  - Time When Resource is Used
  - Unitization
- ABILITY TO ACCOMMODATE PAST, CURRENT AND FUTURE PROGRAM DATA
- STORAGE AND RETRIEVAL OF DIFFERENT TYPES OF INFORMATION:
  - Cost Data
  - Technical Characteristics
  - Programmatic Data
  - CERs
  - Methodological Data
- STORAGE AND RETRIEVAL VIA THREE MODES:
  - Hard Copy
  - Film
  - Magnetic Tape or Disc
- TOTAL SYSTEM INTEGRITY

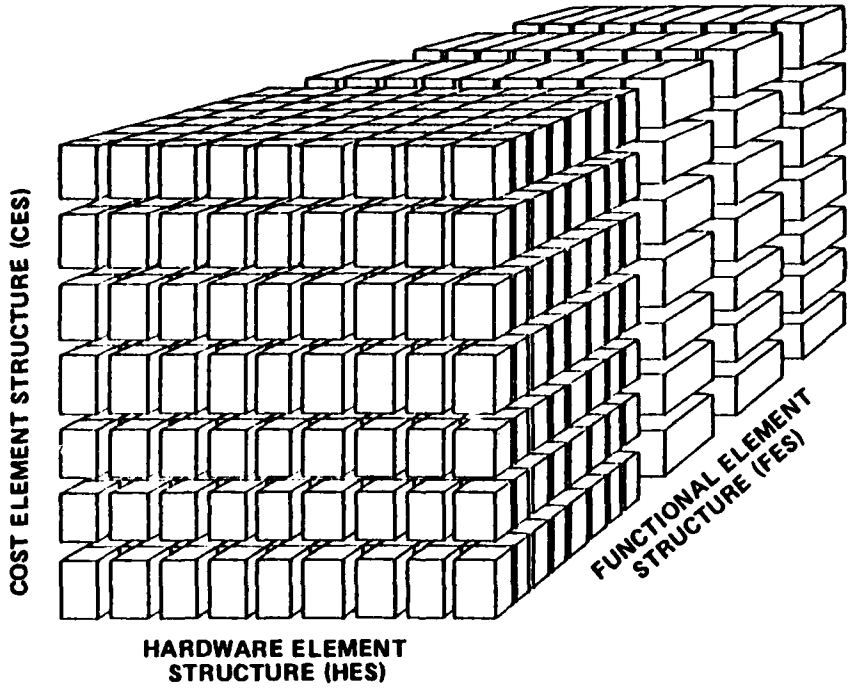
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THE FOUNDATION: A "STANDARDIZED" WORK BREAKDOWN STRUCTURE



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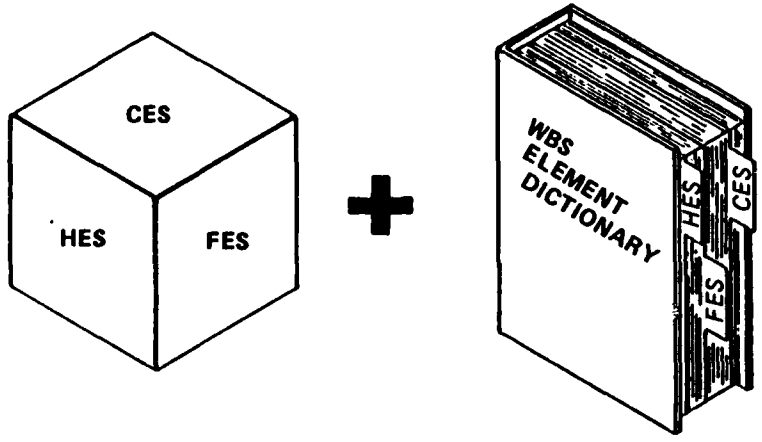
THE THREE DIMENSIONAL CONCEPT



TOTAL PROGRAM COST = SUMMATION OF HARDWARE ELEMENT STRUCTURE
= SUMMATION OF FUNCTIONAL ELEMENT STRUCTURE
= SUMMATION OF COST ELEMENT STRUCTURE

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THE COMPLETE WBS



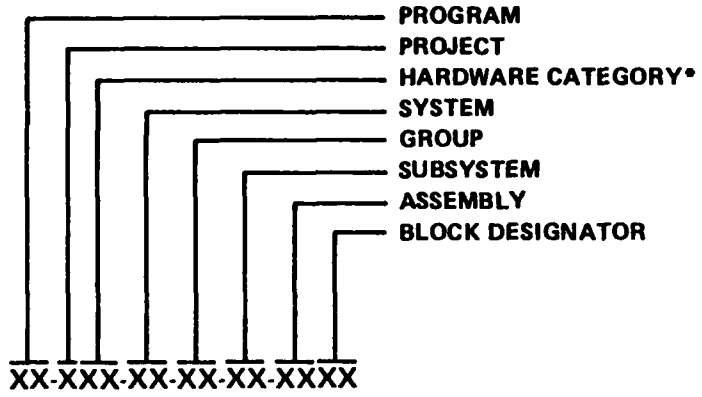
A WBS SYSTEM BASED UPON UNIFORM STRUCTURE AND CONSISTANT CONTENT

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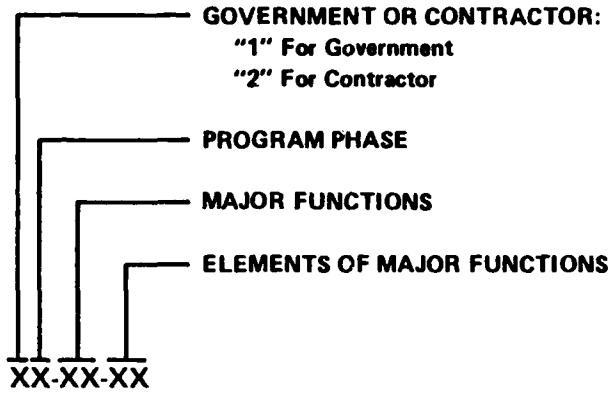
BENEFITS OF THE COMPLETE WBS

- STANDARDIZES
  - Structure
  - Content
  - Coding
  - Terminology
- PROVIDES
  - More Efficient Data Handling
  - Flexibility
  - Expandability
- PROVIDES COST ANALYST WITH MAXIMUM VISIBILITY
  - Recurring/Non-Recurring Breakout
  - To Which End Item (HES)
  - What Resource (CES)
  - How Resource is Used (FES)

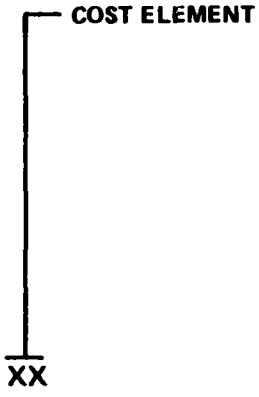
HARDWARE ELEMENT STRUCTURE



FUNCTIONAL ELEMENT STRUCTURE



COST ELEMENT STRUCTURE



* 1 Launch Vehicles
2 Spacecraft
3 Payloads
4 Aircraft
5 Missiles
6 Facilities
7 General

- COMPLETE DOCUMENTATION WAS DEVELOPED:
  - Volume I, System Description
  - Volume II, WBS and Dictionary
  - Volume III, User's Handbook

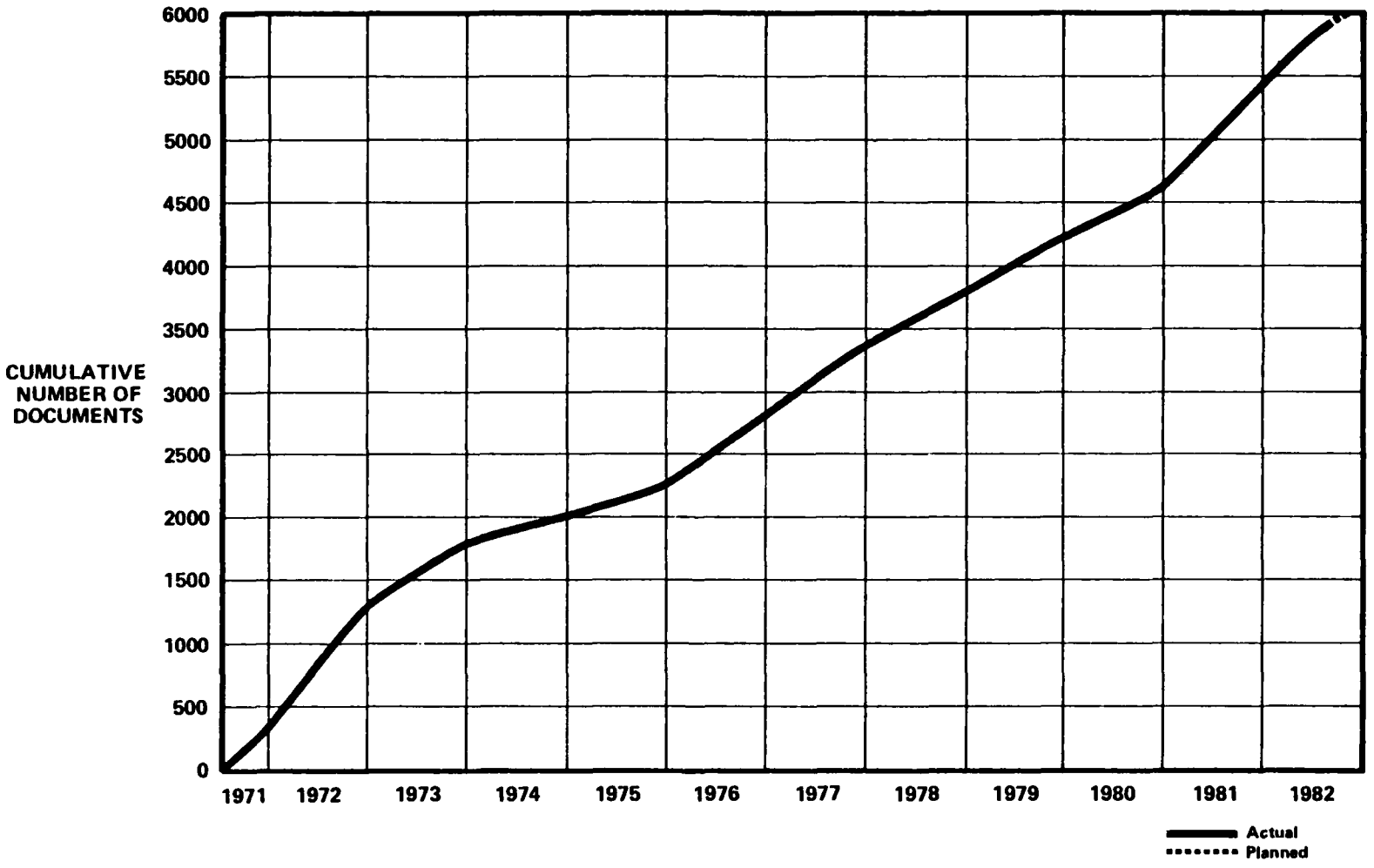
- TOOLS WERE MADE AVAILABLE TO THE COST ANALYST IN THE FORM OF:
  - Computer Mass Memory System (CMS) to Accept and Retrieve Cost, Technical and Programmatic Data
  - Hard Copy and Film System (HCFS) to Store Documents, by Contractor and Subject, Related to;
    - Conceptual Studies and Reports of Systems/Subsystems
    - Design Specifications
    - Technical Descriptions
    - Cost Studies and Models
    - Economic Analyses
    - Etc., Etc., Etc.

- EXTENSIVE BRIEFING MATERIAL IS AVAILABLE TO COVER:
  - Detailed System Operations
  - Input/Output Requirements and Formats
  - Type of Reports

- COST, TECHNICAL AND PROGRAMMATIC DATA FOR:
  - MERCURY
  - GEMINI/AGENA
  - CENTAUR
  - SATURN/APOLLO (S-II, S-IVB, Lunar Module, Apollo Command Module)
- THESE DATA WERE UTILIZED TO ESTIMATE THE AGENCY COMMITMENT TO CONGRESS FOR THE SPACE SHUTTLE PROGRAM

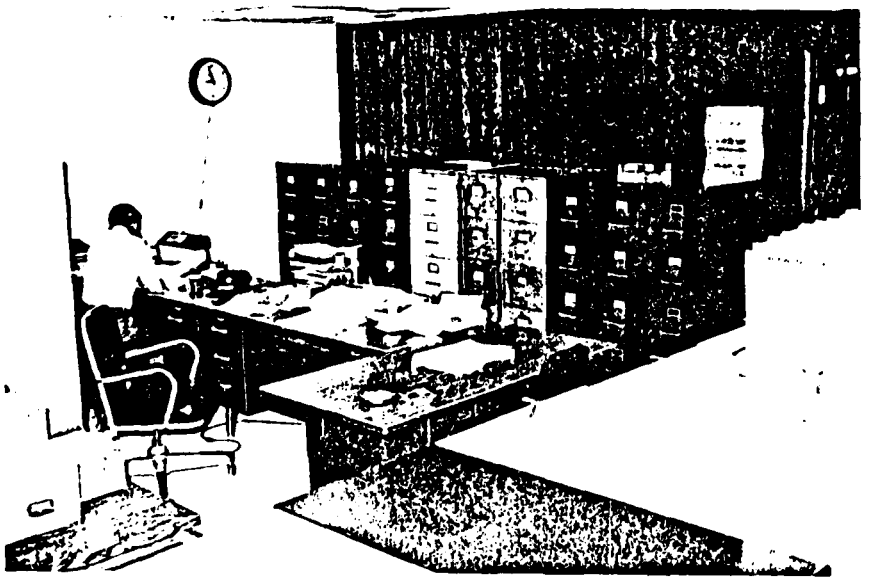
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NUMBER OF DOCUMENTS CONTAINED IN REDSTAR



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REsource Data STorage And Retrieval SYSTEM (REDSTAR)



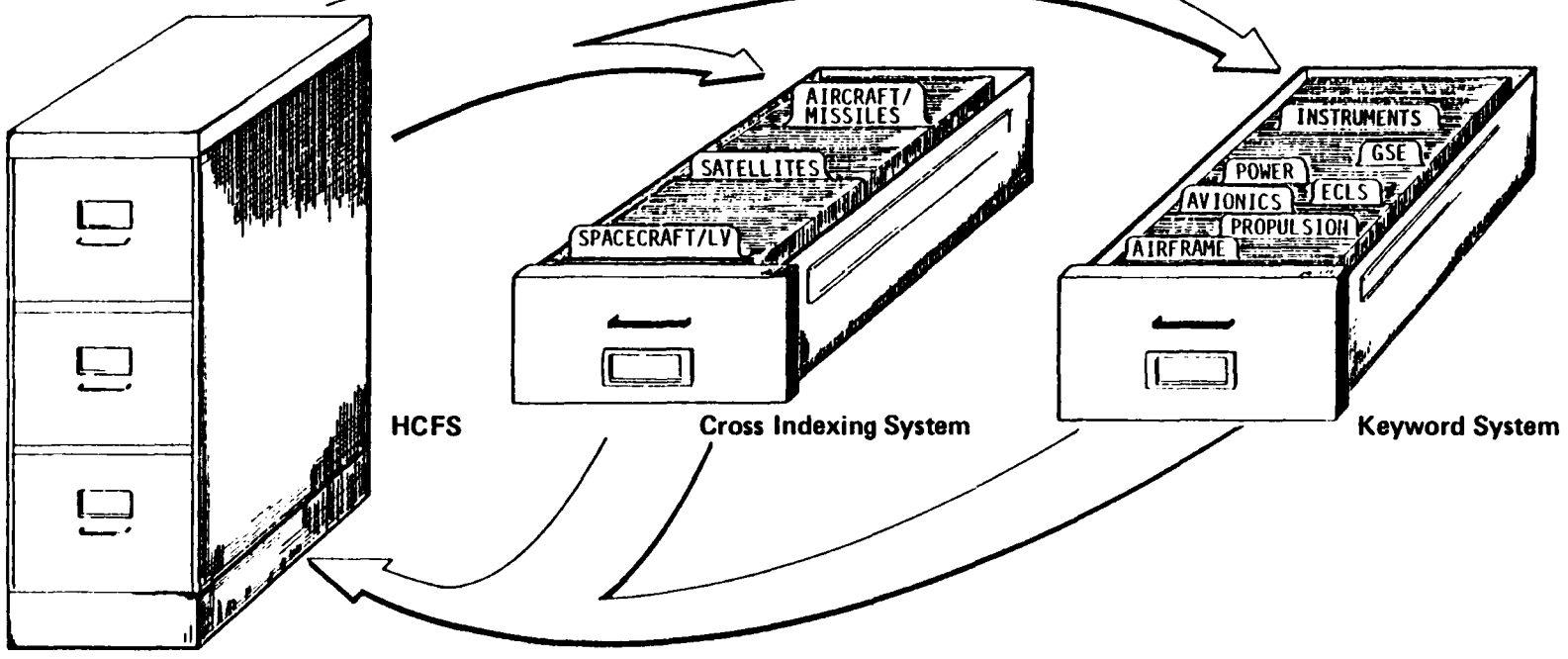
- USED EXCLUSIVELY TO SUPPORT COST ESTIMATING AND ANALYSIS WITHIN THE GOVERNMENT
- SOURCES OF DATA: PRIME CONTRACTORS, DOD, NASA CENTERS, VENDORS, UNIVERSITIES, ETC.



- DATA FORM: HARD COPY & MICROFISCHE
- PHYSICAL SIZE: - ~6000 DOCUMENTS - HARD COPY AND FILM SYSTEM (HCFS)
  - 4000 DATA FOLDERS - EXPERIMENT CROSS REFERENCING SYSTEM (ECRS)
  - 52 FOUR-DRAWER FILE CABINETS 1000 FT. SQ. OF FLOOR SPACE
- PROFESSIONALLY STAFFED ON A FULL-TIME BASIS
- SECURITY REQUIREMENTS: STORED IN SEPARATE LOCKED AREA WITH ADEQUATE FIRE DETECTION AND CONTROL EQUIPMENT

prc

HCFS/CROSS INDEXING AND KEYWORD SYSTEM



DOCUMENTS STORED BY CONTRACTOR

CROSS INDEX CARDS FILED BY:

- Spacecraft/Launch Vehicle
- Satellites
- Aircraft
- Cost Models
- Missiles
- Radars
- Scientific Instruments

KEYWORD CARDS FILED BY HARDWARE ELEMENT STRUCTURE

prc

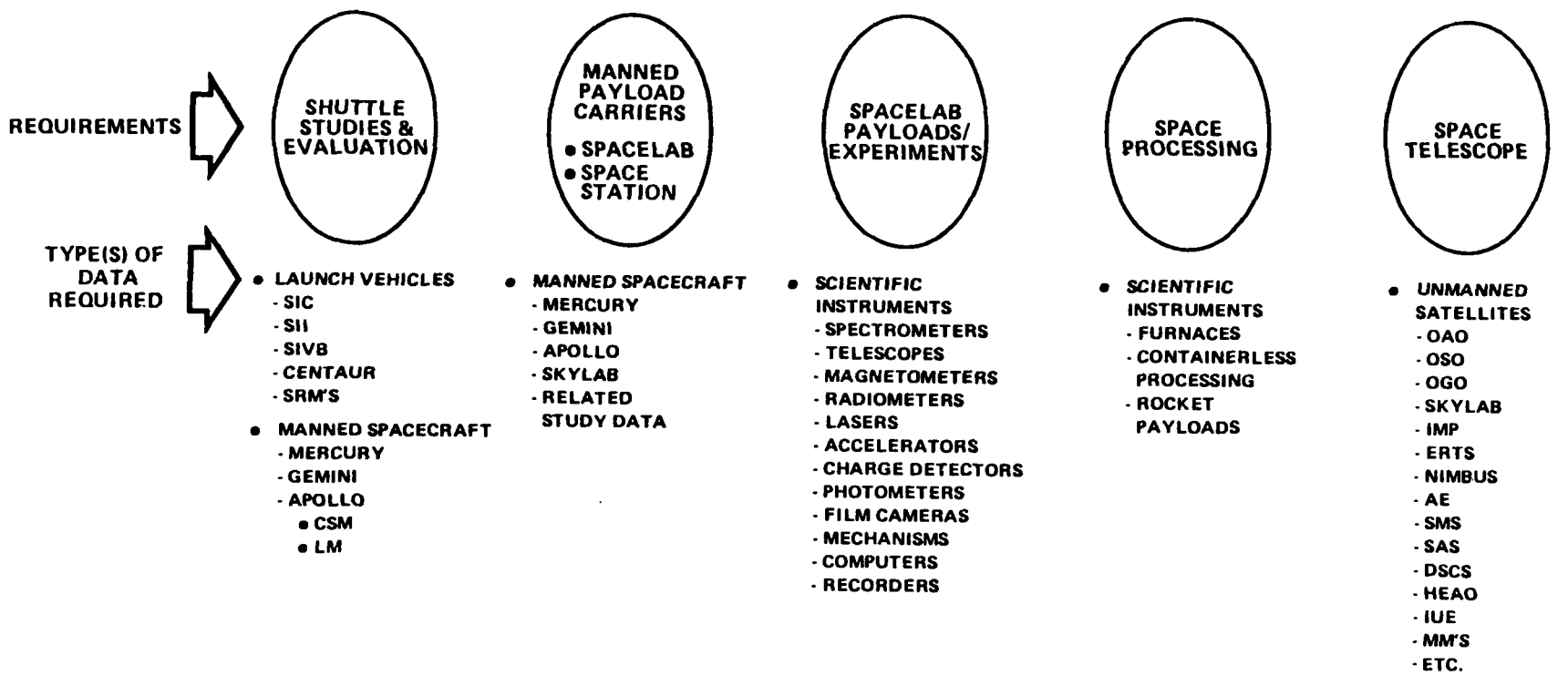
PRESENT CONTENTS AND TYPES OF DATA CONTAINED IN REDSTAR

- PROGRAM DATA
  - SPACECRAFT
    Unmanned (Skylab, HEAO, OAO, OSO, ERTS, NIMBUS, IMP, SAS, Etc.)
    Manned (Apollo, Skylab, Gemini, Shuttle, Mercury, Spacelab)
  - SCIENTIFIC INSTRUMENTS
  - AIRCRAFT
  - HARDWARE ELEMENTS (Solar Arrays, Structure, Composites, Material, Star Trackers, Gyros, Computers, Tape Recorders, Film Cameras, Etc.)
  - SYSTEM STUDIES
  - COST MODELS (NASA, USA, USN, USAF, Private Companies)
  - LAUNCH VEHICLES (SIC, SII, SIVB, Atlas, Titan, SRMs)
  - ROCKET PAYLOADS
  - BALLOON PROGRAMS
  - MISSILE SYSTEMS

- COST, TECHNICAL AND PROGRAMMATIC DATA ARE AVAILABLE AT VARIOUS LEVELS:
  - PROGRAM/PROJECT
  - SYSTEM
  - SUBSYSTEM
  - ASSEMBLY
  - COMPONENT

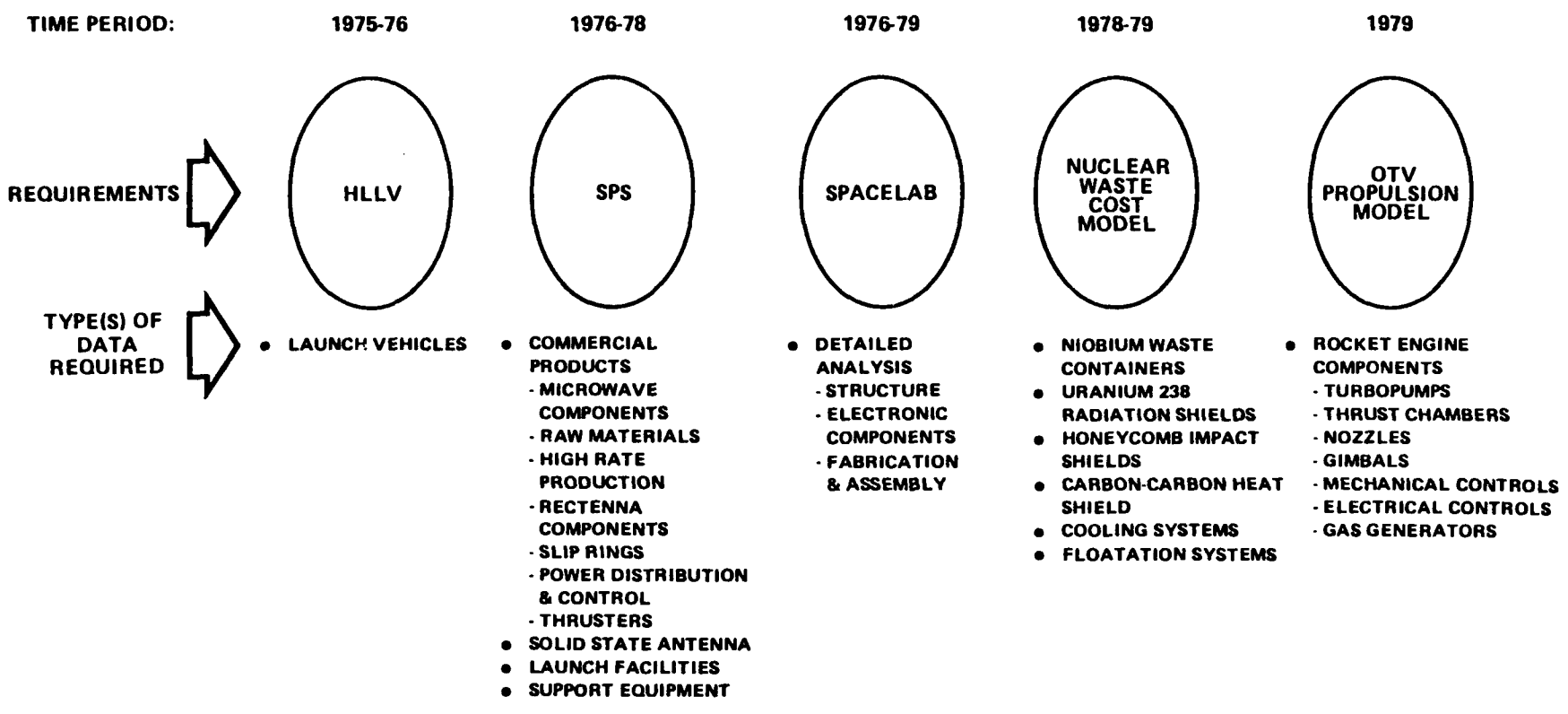
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TODAY REQUIREMENTS DRIVE THE TYPES AND KIND OF DATA NEEDED TO SATISFY THE ANALYSTS REQUIREMENTS



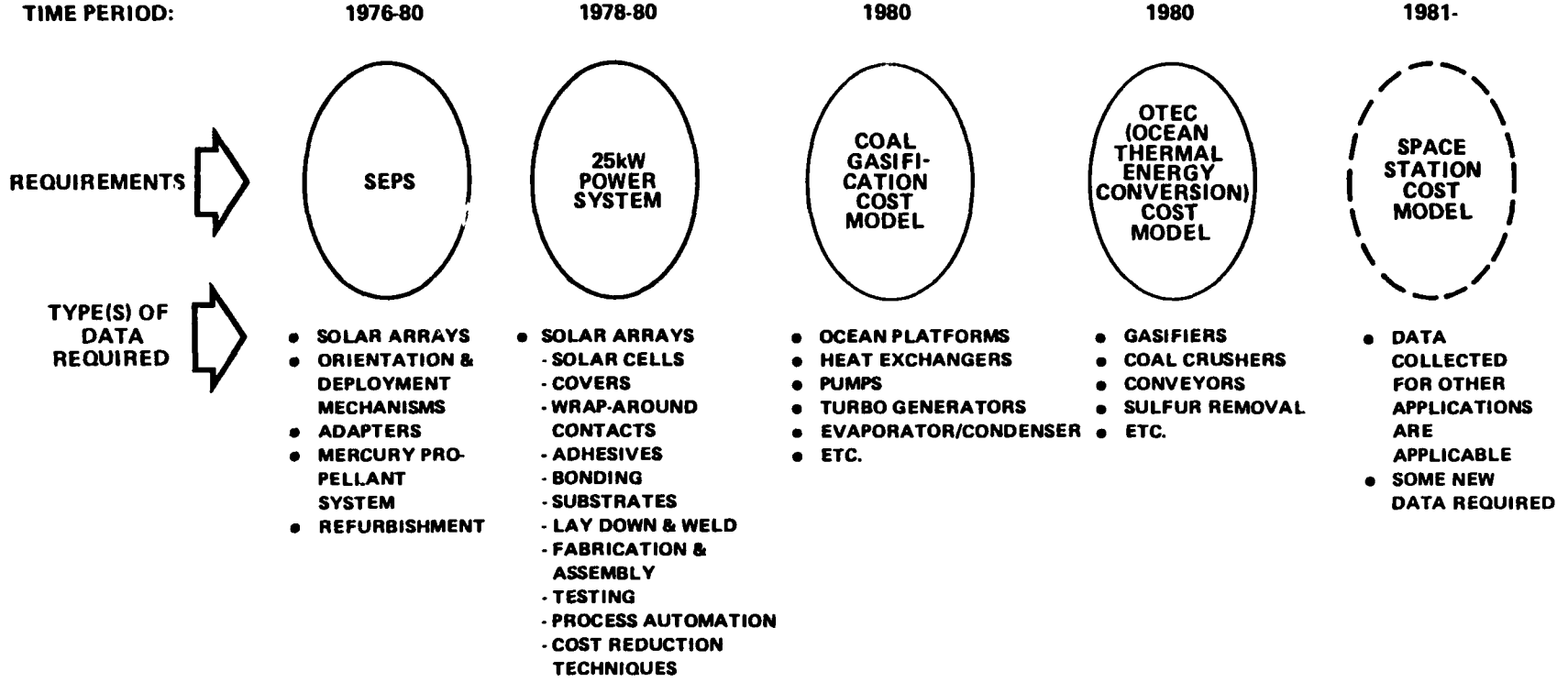
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DAY-TO-DAY REQUIREMENTS DRIVE THE TYPES AND KIND OF DATA NEEDED TO SATISFY THE ANALYSTS REQUIREMENTS (CONTINUED)



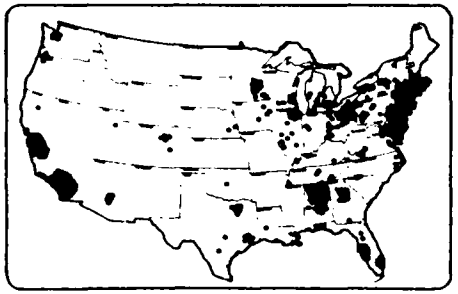
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DAY-TO- DAY REQUIREMENTS DRIVE THE TYPES AND KIND OF DATA NEEDED TO SATISFY THE ANALYSTS REQUIREMENTS (CONTINUED)



prc

TYPICAL SOURCES PROVIDING DATA FOR REDSTAR



HARDWARE MANUFACTURERS (~240)

ABLE ENGINEERING COMPANY
ABR CORPORATION
ACTRON
ADAMS-RUSSELL COMPANY, INC.
AEROVOX
AERTECH INDUSTRIES
AIRESEARCH
AIRTRON
ALCOA ALUMINUM
ALIGNED FIBER COMPOSITES (AFC)
ALLIS-CHALMERS
ALPHA INDUSTRIES, INC.
ALHAMBRA SHEETMETAL
AMERICAN ELECTRONICS LABORATORIES, INC.
AMERICAN FOREST PRODUCTS
AMERICAN SCIENCE AND ENGINEERING (AS&E)
AMF, INC.
AMPLICA, INC.
ANAREN MICROWAVE, INC
ANDREW CORPORATION
ARTCOR, INCORPORATED
ASTRO RESEARCH CORPORATION
ASTRO-MAST
AVANTEK, INC.
AVCO LYCOMING DIVISION
BALL BROTHERS RESEARCH CORPORATION
BARNES ENGINEERING
BEECH AIRCRAFT
BELL & GOSSETT
BENDIX CORPORATION
BIRMINGHAM ORNAMENTAL IRON
BLOCK ENGINEERING
BOEING
BRUNNER MANUFACTURING CORPORATION
BURKS PUMPS
C&H BUILDING SPECIALTY
CABLEWAVE SYSTEMS, INC.
CALIFORNIA EASTERN LABORATORIES, INC
CALUMET FIBERGLASS PRODUCTS
CARCO ELECTRONICS
CENTRAL RESEARCH LABORATORIES, INC.
CHICAGO AERO, INC.
COMMUNICATIONS TRANSISTOR CORPORATION
COMPUTER PRODUCTS, INC.
CONDENSER PRODUCTS
CONIC DATA SYSTEMS
CONSOLIDATED CONTROLS
CONTROL DATA CORPORATION
COOK ELECTRIC
CUSTOM COMPONENT SWITCHES, INC.
CUTLER-HAMMER
DABURN ELECTRONICS AND CABLE CORP.
DAICO INDUSTRIES, INC.
DAVIDSON OPTRONICS
DEARBORN WIRE & CABLE
DELCO WIRE & CABLE
DELTA AIRLINES
DILWORTH LUMBER
DRESSER INDUSTRIES
DURACOTE CORPORATION
DU PONT, INC.
DURA-STRESS
EAGLE-PICHER
EDMUND SCIENTIFIC COMPANY
ELECTRO-MECHANICAL RESEARCH (EMR)
ELECTRO-OPTICS, DIVISION OF XEROX
ELECTRON TUBE DIVISION OF LITTON
EMC TECHNOLOGY, INC.
EMERSON & SUMING
EMERSON ELECTRIC COMPANY
ENMAR CHEMICAL COMPANY
FAIRCHILD-HILLER
FAIRCHILD SEMICONDUCTORS
FAIRCHILD STRATOS
FANSTEEL
FIBER MATERIALS, INC.
FIBERITE CORP.
FLEXIBLE TUBING CORPORATION
FLOTEC, INC.
FRANKLIN INSTITUTE RESEARCH LABORATORY
FREQUENCY CONTOURS, INC.
FREQUENCY DEVICES, INC.
FREQUENCY SOURCES, INC.
FREQUENCY-WEST, INC.
GALILEO ELECTRO-OPTICS CORPORATION
GCA/MCPHERSON
GENERAL AUTOMATION
GENERAL ELECTRIC
GENTRY ASSOCIATES
GILBERT & BENNETT MANUFACTURING CO
GLASTIC CORPORATION
GOLDSWORTHY PULTRUSION
GOULD CORPORATION
GRUMMAN
GTE-SYLVANIA
HAMILTON STANDARD
HARRIS THERMAL TRANSFER PRODUCTS, INC.
HARWOOD ENGINEERING
HERCULES, INC.
HEWLETT-PACKARD
HEXCEL CORPORATION
HONEYWELL
HUBBLE METALS
HUGHES AIRCRAFT COMPANY
HUGHES RESEARCH LAB
HUNTSVILLE NUT & BOLT
HYDRAULIC RESEARCH
HYDRO-POC, INC.
IBM
IEC CORPORATION
IMPERIAL SUPPORT COMPANY
INTERDATA
INTERELECTRONICS CORPORATION
INTERSONICS
ION PHYSICS CORPORATION
ISOMET
ITT ELECTRO-OPTICAL DIVISION
ITT (FT. WAYNE)
JACKSON & MORELAND
JOHNSTON PUMP COMPANY
JOY MANUFACTURING
KDI-ELECTRO-TEC CORPORATION
KEENE CORPORATION
WALTER KIDDE & COMPANY
KING CORPORATION
KINGSTON INDUSTRIES
KLEEN STEEL
KOLLSMAN INSTRUMENT CORPORATION
LEECO PRECISION SPRING MANUFACTURING CO
LENNAN LIGHTS
LIFE SYSTEMS, INC.
LOCKHEED PALO ALTO RESEARCH CENTER
LOCKHEED MISSILE AND SPACE CORPORATION
LORIN INDUSTRIES
LOX EQUIPMENT CO.
LUMMUS COMPANY, HEAT TRANSFER DIVISION
MACHLETT LABORATORY
MARTIN-MARIETTA (DENVER)
MAXWELL LABS
MCDONNELL DOUGLAS
MERRIMAC
METAL BELLOWS, INC.
MICRO-NOW INSTRUMENT COMPANY, INC
MICRO-SWITCH DIVISION OF HONEYWELL
MICROSONICS
MICROWAVE PRODUCTS, INC.
3M COMPANY
MINNESOTA VALLEY ENGINEERING CYROGENICS
MOBIL-TYCO, INC.
MORRISON MOLDED FIBERGLASS CO.
MOTOROLA
NATIONAL SEMICONDUCTORS, INC.
NATIONAL-STANDARD COMPANY
NORDEN DIVISION
NORTHROP ELECTRONICS
NORTHROP (NORAIR)
O'BRIEN MACHINERY COMPANY
ODETICS CORPORATION
OMEGA LABORATORIES, INC.
OPTICAL COATING LABORATORY
OWENS-CORNING FIBERGLASS CORPORATION
PARKER HANNIFIN
PERKIN-ELMER
PHILLYSTRAN RESINS
PHOENIX WIRE WORKS, INC.
POLY-SCIENTIFIC DIVISION OF LITTON INDUSTRIES
PPG INDUSTRIES
PRESSURE SYSTEMS, INC.
PRIME COMPUTER
PRODELIN
PROGRAMMED AND REMOTE SYSTEM CORP
RCA
RFD, INC.
RAYMOND ENGINEERING
RAYTHEON
RAYTHEON STRATEGIC SYSTEMS DIRECTORATE
REPUBLIC COMPANY
REYNOLDS ALUMINUM
RHG ELECTRONICS LABORATORY, INC.
RICHARDSON CONSTRUCTION CO.
ROCKET RESEARCH CORPORATION
ROCKWELL INTERNATIONAL
ROTEK, INC.
SAMSON OCEAN SYSTEMS, INC.
SANDERS ASSOCIATES, INC.
SARGENT INDUSTRIES
SCHMIDT-AMERICAN
SCIENTIFIC-ATLANTA, INC.
SEMICONDUCTOR CIRCUITS, INC.
SEWALL GEAR MANUFACTURING COMPANY
SINGER COMPANY
SKINNER ENGINE COMPANY
SOLAREX
SOUTHEASTERN COMPONENT SALES, INC.
SOUTHERN RESISTANCE WELDING COMPANY
SOUTHERN WOOD
SPACETAC, INC.
SPAR AEROSPACE CORPORATION
SPECTROLAB
SPERRY RAND
STANDARD WIRE & CABLE
STERLING INSTRUMENTS
SUPERIOR CARBON PRODUCTS
SYMETRICS, INC.
TAYCO ENGINEERING
TECHNICRAFT
TELEDYNE
TERRACOM
TEXAS INSTRUMENTS
THOMSON-CSF ELECTRON TUBES, INC.
TINSLEY LABS
TOBE DEUTSCHMANN
TRAK MICROWAVE CORPORATION
TRANSICIRCUITS, INC.
TRANSILWRAP COMPANY
TRANTER, INC.
TRG-ALPHA INDUSTRIES
TRW, INC.
TYLER INDUSTRIAL PRODUCTS
ULLRICH COPPER
UNIFORM TUBES, INC.
UNIMATION, INC.
UNION CARBIDE
UNITED EQUIPMENT ACCESSORIES, INC.
UP-RIGHT SCAFFOLD
VACCO INDUSTRIES
VACUMET
CALTEC CORPORATION
VARIAN COMPUTER
VARIAN MICROWAVE
VECTOR LABORATORIES, INC.
A. T. WALL COMPANY
WATKINS-JOHNSON COMPANY
WESTERN UNION
WESTINGHOUSE
WESTON CORPORATION
WEYERHAUSER WOOD
WINTEC DIVISION OF BRUNSWICK
WORTHINGTON COMPRESSORS
YODER COMPANY

UNIVERSITIES & NOT-FOR-PROFIT ORGANIZATIONS (~28)

AEROSPACE CORPORATION
BOWLING GREEN STATE UNIVERSITY
CALIFORNIA INSTITUTE OF TECHNOLOGY
HARVARD COLLEGE
IITRI
INSTITUTE FOR DEFENSE ANALYSIS INSTITUTE
JOHNS HOPKINS UNIVERSITY - APL
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
MCDONALD OBSERVATORY
MT. PALOMAR
PRINCETON UNIVERSITY
RUTGERS UNIVERSITY
SMITHSONIAN ASTROPHYSICAL OBSERVATORY
STANFORD UNIVERSITY
TEMPLE UNIVERSITY
UNIVERSITY OF CALIFORNIA - BERKELEY
UNIVERSITY OF CALIFORNIA - LA
UNIVERSITY OF CALIFORNIA - SD
UNIVERSITY OF CHICAGO
UNIVERSITY OF COLORADO
UNIVERSITY OF IOWA
UNIVERSITY OF MARYLAND
UNIVERSITY OF MICHIGAN
UNIVERSITY OF MINNESOTA
UNIVERSITY OF NEW HAMPSHIRE
UNIVERSITY OF TEXAS
UNIVERSITY OF VIRGINIA
UNIVERSITY OF WISCONSIN

GOVERNMENT AGENCIES (~50)

AIR FORCE CAMBRIDGE RESEARCH LABORATORY (AFCRL)
AIR FORCE ROCKET PROPULSION LAB - EDWARDS AFB
AMES RESEARCH CENTER (ARC)
ARNOLD ENGINEERING DEVELOPMENT CENTER (AEDC)
ATLANTA FEDERAL RECORD CENTER
BONNEVILLE POWER ADMINISTRATION
CORPS OF ENGINEERS
DEPARTMENT OF DEFENSE
GODDARD SPACE FLIGHT CENTER (GSFC) 19 PROJECT OFFICES
HEADQUARTERS NAVAL AIR SYSTEMS COMMAND (NAVAIR)
HEADQUARTERS NAVAL SEA SYSTEMS COMMAND (NAVSEA)
HIGH ALTITUDE OBSERVATORY (HAO)
JET PROPULSION LABORATORY (JPL)
JOHNSON SPACE CENTER (JSC)
KITT PEAK NATIONAL OBSERVATORY (KPNO)
LANGLEY RESEARCH CENTER (LaRC)
LAWRENCE LIVERMORE LABORATORY
LEWIS RESEARCH CENTER (LeRC)
MARSHALL SPACE FLIGHT CENTER (MSFC)
NASA HEADQUARTERS
NASA - LC 10
NATIONAL RADIO ASTRONOMY OBSERVATORY
NAVAL RESEARCH LABORATORY (NRL)
NAVAL WEAPONS CENTER
NOAA (DEPARTMENT OF COMMERCE)
OFFICE OF CHIEF OF NAVAL OPERATIONS (CNO)
REDSTONE SCIENTIFIC INFORMATION CENTER (RSIC)
TVA
U.S. AIR FORCE BASE (ESD)
USAF SPACE AND MISSILE SYSTEMS ORGN (SAMSO)
WRIGHT-PATTERSON AFB (ASD)

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- A FEW OTHER SOURCES OF DATA
  - REDSTONE SCIENTIFIC INFORMATION CENTER (RSIC)
  - DEFENSE TECHNICAL INFORMATION CENTER - DTIC (Was DDC)
  - DEPARTMENT OF ENERGY TECHNICAL INFORMATION CENTER (Oak Ridge, Tn)
  - NTIS-NATIONAL TECHNICAL INFORMATION CENTER
  - NASA LIBRARY
  - NASA STAR SYSTEM
  - GAO REPORTS
  - AVIATION WEEK (Weekly, Special Issues and Marketing Guide)
  - TRADE JOURNALS
  - MANUFACTURING HANDBOOKS
  - HISTORICAL OFFICES (RSA, WASHDC, WPAFB, Etc.)
  - PROGRAM/PROJECT OFFICES
  - GOVERNMENT LIBRARIES AT ALL MAJOR INSTALLATIONS
  - TECHNICAL SOCIETIES (SOLE, AACE, Etc.)
  - PUBLIC RELATIONS OFFICES
  - LIBRARY OF CONGRESS
  - GOVERNMENT PRINTING OFFICE
  - MSFC REPOSITORY
  - SOLAR ENERGY INFORMATION DATA BANK
  - U.S. DEPARTMENT OF THE INTERIOR EROS DATA CENTER
  - MICOM LIBRARY
  - THOMAS REGISTER
  - NATIONAL SPACE SCIENCE DATA CENTER
  - NES MEMBERS (Local and National)

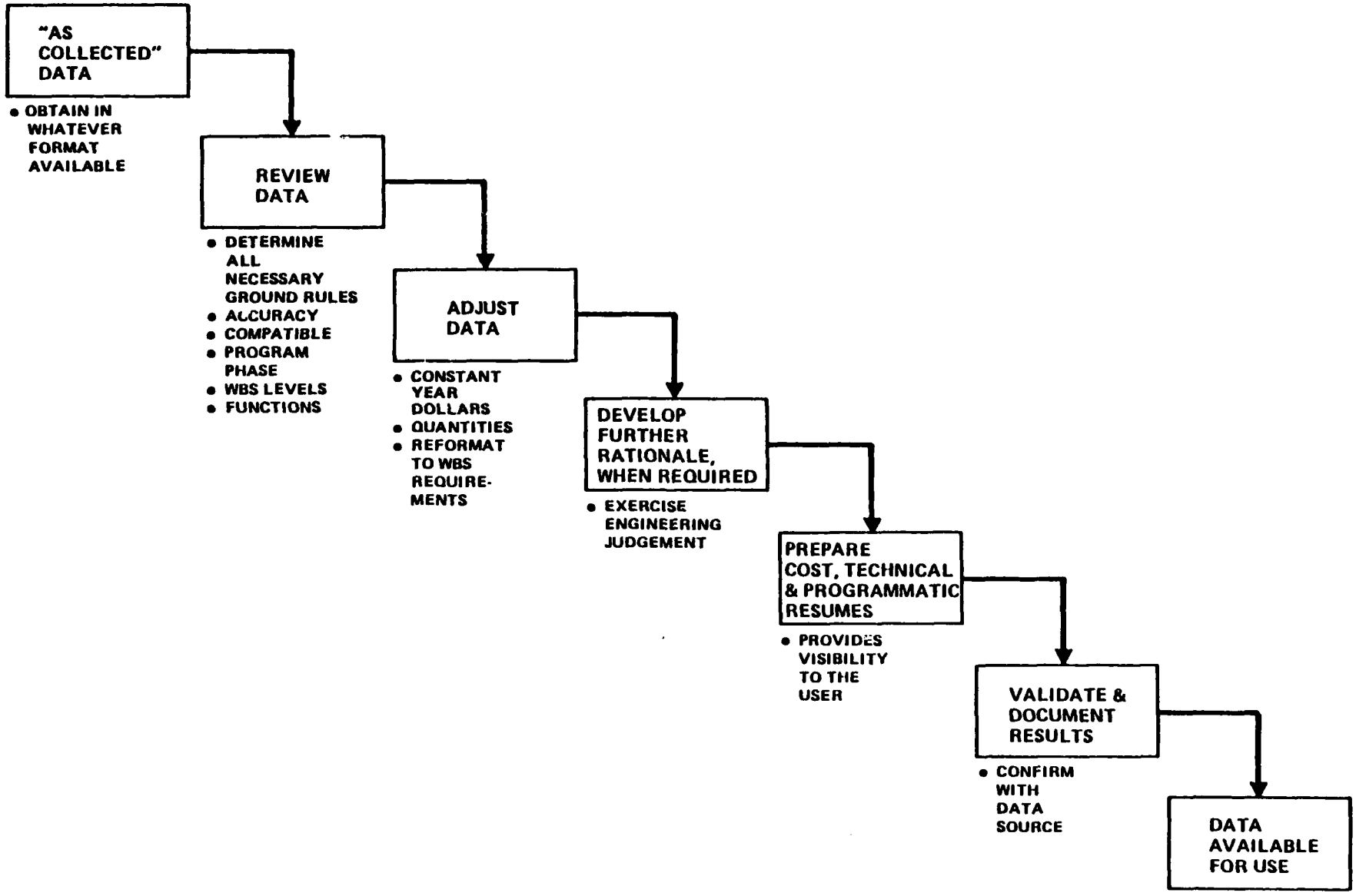
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TYPICAL PROBLEMS ENCOUNTERED IN DATA COLLECTION

- THE OLDER THE PROGRAM/PROJECT, THE HARDER IT IS TO OBTAIN ACCURATE AND RELIABLE DATA
- DISPOSAL OF RECORDS AND RECORD RETENTION FILES
- TRANSFER OR TERMINATION OF COGNIZANT PERSONNEL
- KEY PERSONNEL CURRENTLY WORKING ON ON-GOING PROGRAMS ARE PRESSED FOR TIME, AND ARE OFTEN RELUCTANT TO SPEND TIME "DIGGING" OUT DATA
- PRIOR DOCUMENTATION PROVIDED TO THE GOVERNMENT . . . (WHY DO I HAVE TO DO IT AGAIN?)
- IN-HOUSE EFFORTS/RECORDS DO NOT PROVIDE THE DESIRED LEVEL OF VISIBILITY
- SUCCESS DEPENDS ON THE SOURCE ORGANIZATION, PROGRAM/PROJECT OF INTEREST AND THE SPECIFIC DATA DESIRED:
  - 60% Obtained from available records/interview notes
  - 30% from refferrals, other locations and follow-up
  - 10% may never be cost-effectively collected

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ONCE YOU HAVE THE DATA - - - PROPER INTERPRETATION IS THE MOST IMPORTANT ASPECT TO CONSIDER PRIOR TO USE



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DATA ANALYSIS - TECHNICAL RESUMES ARE PREPARED TO PROVIDE THE USER WITH INSIGHT INTO THE DATA

TECHNICAL RESUME

NAME: APOLLO TELESCOPE MOUNT - SOLAR ARRAY PROJECT: SKYLAB

ACRONYM: ATM SAS LAUNCH DATE: MAY 14, 1973

CENTER: MARSHALL SPACE FLIGHT CENTER - HUNTSVILLE, ALABAMA

PRINCIPAL SUBCONTRACTORS: SPECTROLAB/SJ INDUSTRIES

SOLAR ARRAY SYSTEM DESCRIPTION:

The ATM SAS consisted of 20 solar panels divided into four wings.

The ATM SAS was designed to proivde nominal predicted output of 10,343 W at EOM, at a temperature of 55°C and an intensity of 140 mW/cm^2 at air mass zero (AMO). The beginning-of-mission (BOM) predicted power was 11,340 W for the same conditions.

Each solar array wing consisted of 4 complete panels each containing 20 SCMs and a half-panel containing 10 modules. The four half-panels, one from each wing, were paired to form two complete panels, making a total of 18 complete panels in the array.

Individual panels were connected to Charger/Battery/Regulator Modules (CBRMs) which were in turn connected in parallel to the ATM load bus.

Each of the 18 panels was an independent power source consisting of either 2 pairs of 10 or 20 SCMs electrically connected in parallel.

The basic building block of a solar panel was the SCM. Two module configurations were used, one configuration consisted of 228 2 x 6 cm solar cells with 2 cells in parallel by 114 cells in series. The other configuration consisted of 684 2 x 2 cm solar cells with 6 cells in parallel by 114 in series.

PHYSICAL AND ELECTRICAL CHARACTERISTICS OF THE ATM SAS

ARRAY

Size	521 in. long, 104.5 in. wide (per wing
Weight	4,300 pounds (including deployment structure)
Panels per Wing	5 (inboard panels were half covered with modules)
Total Panels	20 individual, 10 "electrical" panels
Total Solar Cells	
2 x 2 cm	123,120
2 x 6 cm	41,040 TOTAL SOLAR CELLS: 164,160
Total Modules	360
Total Array Power Output	11,340 W (at 55°C at BOM) Nominal 10,343 W (at 55°C at BOM) Prediction

SOLAR CELL MODULE DESCRIPTION:

Two types of modules were used on the ATM. (Industries and the other type was manufactured by utilized 2 x 2 cm cells, arranged 6 in parallel by silver mesh interconnects. The Spectrolab module 2 in parallel by 114 in series, and copper bar int size, the type of interconnects, and some of the modules were the same.

s 20.00 x 24.62 inc
nch thick. The fac
heet on the opposit
Cells on each modu
connected in paral
2 cm cells). Mica
ere 0.014-inch thic
fficient with 7 to
ng 7940 fused silic
he cell side and an
he modules was 22 g
ules used the same
tanium solder cover

ICAL CHARACTERISTIC

ypes)

in. long, 24,625 i

8 pounds

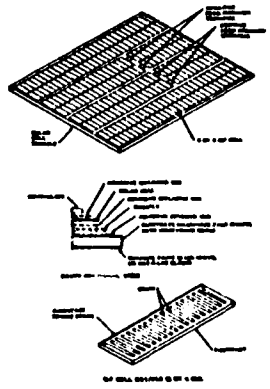
nded silver mesh
er-plated copper

5-inch Silastic 140

inum facesheet/Aluminum honeycomb

5-inch (typical) Micaply

W (overall average at 28°C, BOM)



SPECTROLAB SOLAR CELL MODULE CONSTRUCTION

PANEL DESCRIPTION:

The panels are 265 x 262 cm (8 ft. 8 in. x 8 ft. 7 in.) and are hinged together to permit folding for launch storage. There are 20 modules mounted on each of 16 panels; 10 modules are mounted on each of the 4 inboard panels. Electrically, there were 18 panels, each with 20 modules wired in parallel. Two configurations of the modules were used. One configuration consisted of 684 2 x 2 cm solar cells with 6 cells connect in a parallel subgroup by 114 subgroups connected in series. The other configuration consisted of 228 2 x 6 cm solar cells with 2 cells connected in a parallel subgroup by 114 subgroups connected in series. Each panel was made exclusively of only one of the two module configurations described. Half of the panels were fabricated using 2 x 2 cm cell modules and the other half used the 2 x 6 cm cell modules.

PHYSICAL AND ELECTRICAL CHARACTERISTICS OF THE SOLAR PANEL

SOLAR PANEL

Size	104.3 in. long, 104.5 in. wide
Weight	146 pounds (including panel frame)
Modules per Panel	20 (inboard panels contain 10 modules each)
Total Cells per Full Panels 2 x 2 cm	13,680, or
2 x 6 cm	4,560
Solar Panel Power	630 W (at 55°C at BOM) 574 W (at 55°C at EOM) (Based on 18 electrical panels)

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AN EXAMPLE OF A PROGRAMMATIC RESUME

PROGRAMMATIC RESUME

NAME Return Beam Vidicon FLIGHT PROJECT LANDSAT-1

TEST ARTICLES

- Feasibility model/Engineering Model
- Prototype model
- Test Equipment

FLIGHT UNITS

- Two (2) Flight Units (3 cameras - each)
- One camera provided as spare

Note: 1 flight unit refurbished prototype

PERIOD OF PERFORMANCE

Design Study (NAS5-11621)

Design study report	January 1969
Ruggedized vidicons (fab, test & assy)	July 1970
Feasibility model (fab, test & assy)	July 1970

Hardware Contract (NAS5-21094)

Design study report	March 1970
Engineering model (fab, test, integ & ship)	September 1970
Flight A model (fab, integ & test)	September 1971
Flight B model (fab, integ & test)	February 1972

Note: Also see comments

TYPE OF CONTRACT

CPFF

PROGRAMMATIC RESUME (Continued)

MAJOR GFE

None

MAJOR SUBCONTRACTORS

None

MAJOR MODIFICATIONS

- Changed from Oxide cathode to deepenser cathode
- Before flight, unit A had the vidicon tubes replaced and consequently Flight Unit B flew first

SCHEDULE CHANGES

None

FUNCTIONAL ACTIVITIES

- Design and Development contract hardware contract

COMMENTS

The RBV hardware contract (NAS5-21094), initiated in January 1970, was preceded by an RBV design study contract (NAS5-11621) which was initiated in October 1968.

The feasibility model was a single camera model and was later reworked to produce the engineering test model, also a single camera unit. Both flight models were three camera units; one camera unit was provided as a spare. A prototype model was constructed and then refurbished as flight model A.

prc

DATA ANALYSIS - THE DESIGN/TEST COMPLEXITY MATRIX PROVIDES VALUABLE TOOLS FOR THE NORMALIZATION OF DATA AND INTERPRETATION OF CERS

ITEM: SPACECRAFT PROJECT: HEAO-A SOURCE: HEAO PROJECT OFFICE DATE PREPARED: MARCH 9, 1979

SUBSYSTEM		PERCENT INHERITED	PERCENT NEW DEVELOPMENT	PERCENT NEW DESIGN	MODIFICATION		BREADBOARD OR BRASSBOARD (NOTE 1)	DEVELOPMENT MODEL		QUALIFICATION		FLIGHT HARDWARE ACCEPTANCE TESTING (NOTE 2)
					PERCENT	PERCENT REDESIGN		(NOTE 1)	(NOTE 2)	(NOTE 1)	(NOTE 2)	
STRUCTURE		-	-	100	-	-	-	-	-	-	-	-
MECHANICAL		50	-	40	10	25	-	100	1, 3	100	3	16
THERMAL		-	-	100	-	-	-	-	-	-	-	7
EPS	BATTERY	50	-	-	50	50	-	100	7	100	9, 7, 14	9, 7, 14
EPS	SOLAR ARRAY	80	-	20	-	-	-	100	8, 13	100	2	2
EPS	CONTROLS	-	-	100	-	-	-	-	-	-	-	-
COMMUNICATION, COMMAND AND DATA MGMT		50	-	25	25	20	50	-	-	100	1, 9, 7, 11, 14, 17	9, 8, 14
ATTITUDE CONTROL AND DETERMINATION		30	10	50	10	20	50	100	1, 9, 7, 8, 17	100	1, 9, 7, 17	9, 7, 8, 14
RCS PROPULSION		90	-	-	10	5	-	-	-	100	1, 4, 9, 7, 14	9, 14, 10
GROUND SUPPORT EQUIPMENT		-	-	50	50	50						
SOFTWARE	GROUND	-	-	50	50	50						
SOFTWARE	FLIGHT	-	-	50	50	50						

SYSTEM LEVEL TESTING		NOTE 2 TEST LEGEND
(NOTE 2)	NUMBER OF TESTS OR DURATION	
2, 4	1	1. PYROSHOCK
1	1	2. ACCOUSTICS
7	1	3. STATIC LOAD
17	1	4. VIBRATION
5 (SOLAR ARRAY)	4	5. DEPLOYMENT
18. a) NOTE 3	130 HOURS	6. THERMAL BALANCE
b) NOTE 4	10 DAYS	7. THERMAL VACUUM
c) NOTE 5	3 WEEKS	8. THERMAL CYCLING
		9. RANDOM VIBRATION
MOCKUPS AND SIMULATORS		10. PROOF
- STRUCTURAL MOCKUP FOR ELECTRICAL HARNESS LAYOUT		11. ACCELERATION
		12. SHOCK
		13. LIFE
		14. LEAK
		15. BURST
		16. LOT ACCEPTANCE
		17. EMI
		18. ELECTRICAL
		a) ALIVE
		b) FUNCTIONAL
		c) PERFORMANCE BASELINE

NOTE:
1. EQUIVALENT SUBSYSTEM HARDWARE COMPLEXITY OR COST PERCENTAGE
2. REFER TO RIGHT HAND CORNER OF EXHIBIT FOR LEGEND
3. TELEMETRY TEST WITHOUT EXTERNAL STIMULUS (HOURS OF TESTING)
4. TELEMETRY TEST WITH EXTERNAL STIMULUS (DAYS OF TESTING)
6. TELEMETRY TEST WITH SPECIAL GROUND INSTRUMENTATION TO INJECT SIGNAL/STIMULUS BY HARDWARE (WEEKS OF TESTING)

DATA POINT CHARACTERISTICS SUMMARY
STRUCTURE/ENVIRONMENTAL PROTECTION

Parameters	CATEGORY 2				
	ATS 6 (203)	OSO H (205)	Titan M (206)	ATS 5 (209)	VELA IV (211)
Total Weight (lbs.)	941	324	253	307	88
Structure	815	109			83
Environmental Protection					5
Dimensions					3 ft. 10 in. length 4 ft. 7 in. diameter
Volume					61 cu. ft.
Type of Material					Titanium Alloy and Aluminum
Type of Construction					Machined and welded
Type of Environmental Protection					Thermal blankets.
General Description					A spherical pressure vessel fabricated from 6 AL.-4V titanium alloy honeycomb machined and welded. Twenty-four sides covered by solar cells, detectors mounted on twelve corners.
Comments					Nuclear explosion detection satellite. Prime function required stable instrument platform. 3-axis controlled.

DATA POINT CHARACTERISTICS SUMMARY
STRUCTURE/ENVIRONMENTAL PROTECTION

Parameters	CATEGORY 1				
	Skylab OWS (100a)	Apollo Command Module (101a)	Apollo Service Module (101b)	Apollo SLA (101c)	LM - Ascent (102a)
Total Weight (lbs.)	22,485	4,499	5,103	3,997	1,365
Structure	21,627	4,499	4,901	3,997	1,365
Environmental Protection	858	(1)	202	(1)	(1)
Dimensions	58 ft. 7 in. length 21 ft. 8 in. diameter	8 ft. 7 in. length 12 ft. 6 in. diameter	12 ft. 9 in. length 12 ft. 8 in. diameter	28 ft. length 21 ft. 8 in. diameter aft	9 ft. 4 in. length 13 ft. 8 in. diameter
Volume	22,000 cu. ft.	375 cu. ft	1,671 cu. ft.	N/A	235 cu. ft. crew area
Type of Material	7075-T6 Aluminum	Aluminum weldment and brazed steel honeycomb	Bonded aluminum honeycomb	Monocoque	Aluminum with titanium used for fittings and fasteners.
Type of Construction	Skin, rings and stringer	Weld and epoxy bonding honeycomb	Cylinder with bulkhead at each end and tunnel thru the center	Truncated conical fairing	Welded shell externally stiffened
Type of Environmental Protection	High performance insulation	Ablation shield	30 layers of 0.00015 aluminum mylar film and kapton polyamide film	Thermal paint	Enveloped by a thermal and micrometeoroid shield
General Description	The structure consists of the following: • Pressurized cabin structure • Forward skirt • Aft skirt • Propellant tank • Aft Interstage Mechanisms include a forward entry hatch.	The structural and thermal protection features of the CM consist of the following: • A primary load-carrying inner structure • Ablation shield • Hatches and windows • Attachments & disconnects	The structure consists of the following: • Aft bulkhead • Forward bulkhead • Radial beams • Attachments • Access provisions	Located in the Saturn V stack between the S-IVB boosters and the Service Module. Houses the LM during lift-off and translunar insertion.	Consists of three main sections, a cylindrical (92" diameter) pressurized open compartment; an elliptical pressurized mid-section, and an aft unpressurized equipment bay.
Comments	OWS is a modified S-IVB stage. The thrust structure cost and weight were removed.	Excludes heat shield. High cost of Apollo Program reflected. High complex structure High degree of reliability required.	Structure provides load path between boost vehicle and CM during launch phase of mission. High cost of Apollo Program reflected. High complex structure.	Low complex structure	Housed the Lunar Landing crew Reflects the high cost of the Apollo Program Weight constrained design Housed LM Ascent Engines.

(1) Included in Structure Weight

prc

COMPOSITE CER FOR PRIMARY STRUCTURES - DESIGN AND DEVELOPMENT

A

CER Equation	Correlation Coefficient	Standard Error	CER Equation	Correlation Coefficient	Standard Error
$C_1 = 0.1757 Wt^{0.6065}$	0.8517	0.7701	$C_3 =$		
$C_2 =$			$C_4 =$		

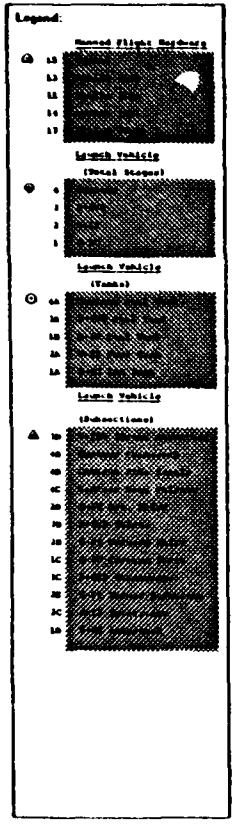
CER for STRUCTURES

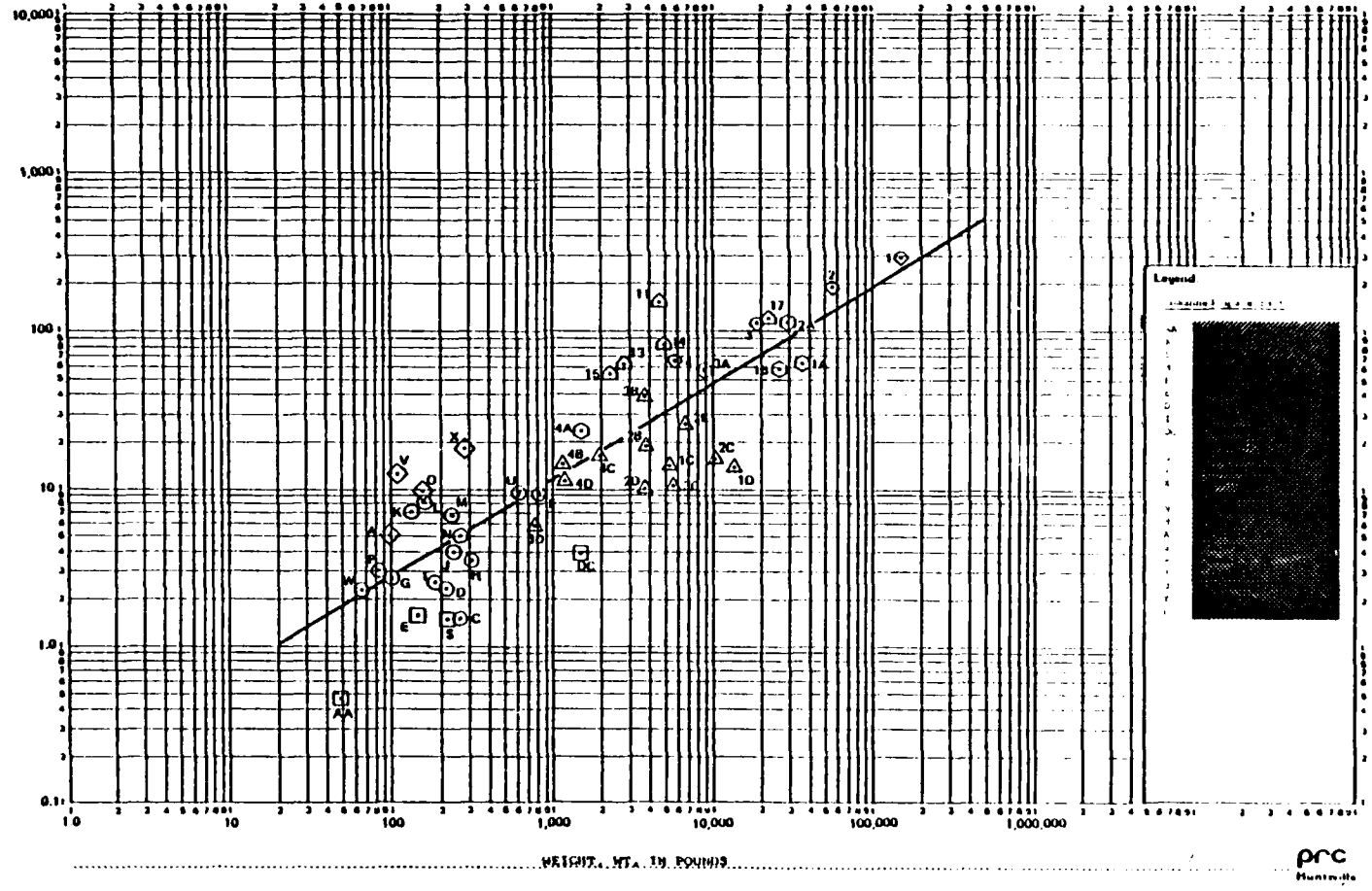
DDT&E ☐ D&D ☒ PFA (or TFU) ☐ FIH ☐

Other

Prepared by T. SMITH Reference Model DATA BOOKS

Date 8-8-80





B

CER Equation	Correlation Coefficient	Standard Error
C1 = $1.1976WT^{0.4633}$	0.9999	0.0071
C2 = $6.021WT^{0.3174}$	0.6582	0.2906
C3 = $1.6049WT^{0.3767}$	0.8736	0.2484
C4 = $2.6114WT^{0.2140}$	0.4100	0.4078

CER Equation	Correlation Coefficient	Standard Error
C5 = $0.140WT^{0.865}$	0.760	0.305
C6 = $0.192WT^{0.569}$	0.824	0.289
C7 = $0.065WT^{0.577}$	0.952	0.231

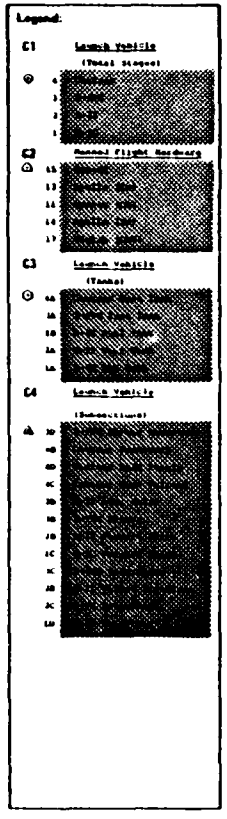
CER for STRUCTURES

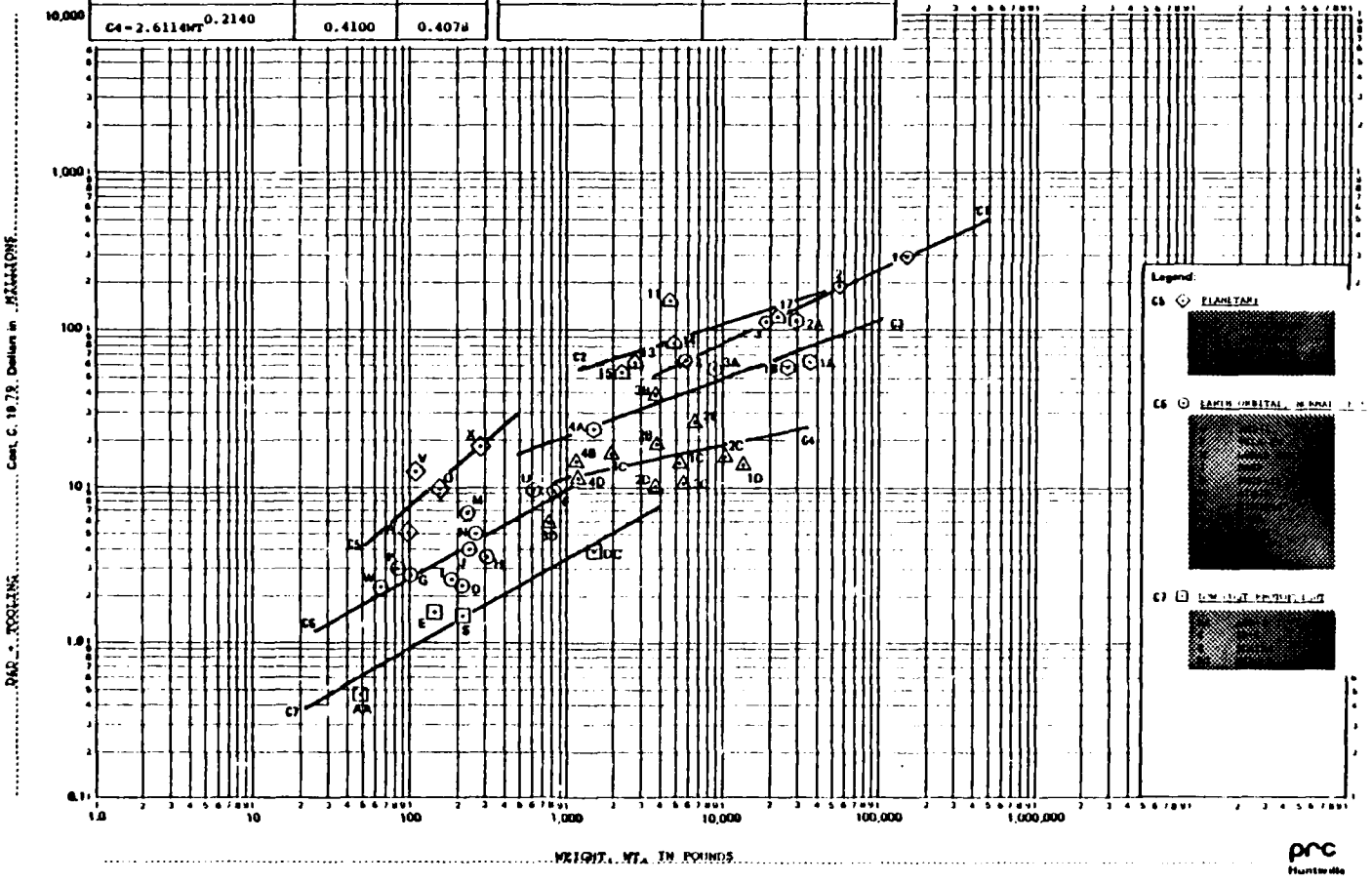
DDT&E ☐ D&D ☒ FFA (or TFU) ☐ FH ☐

Other

Prepared by T. SMITH Reference Model DATA BOOKS

Date 8-8-80





prc Huntsville

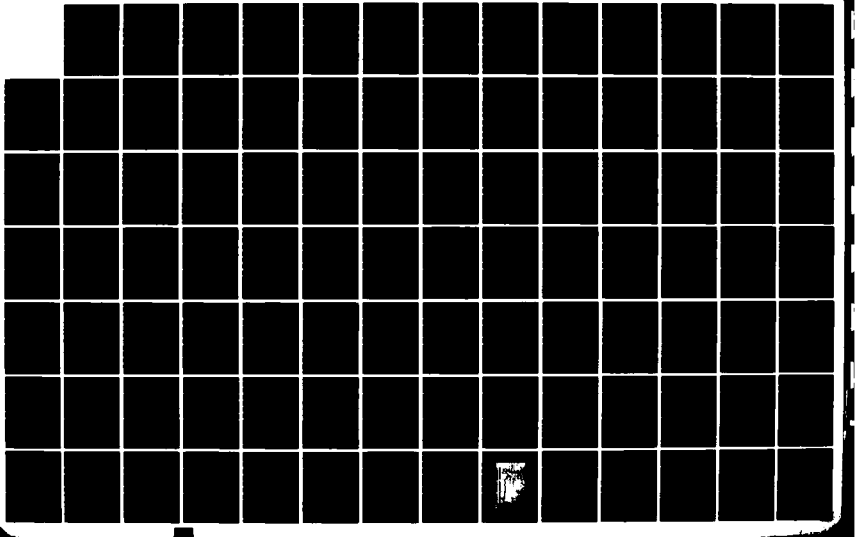
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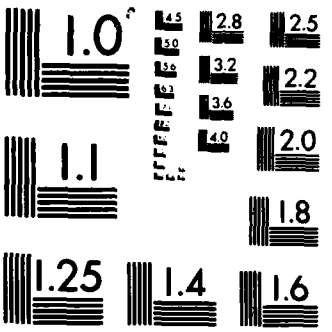
SUMMARY

- REDSTAR DID NOT HAPPEN OVERNIGHT
- REDSTAR IS A COMPREHENSIVE DATA BASE USED EXCLUSIVELY FOR COST ESTIMATING AND ANALYSIS OF:
  - Conceptual Programs
  - Full Scale Development Programs
  - Analysis of On-Going Programs
  - Cost Trade Studies
  - Calibration of Other Cost Estimates
  - Budget Requests

AD-A130 418 DEPARTMENT OF DEFENSE ANNUAL COST ANALYSIS SYMPOSIUM (17TH) HELD AT ARLINGTON VIRGINIA ON 12-15 SEPTEMBER 1982(U) OFFICE OF THE CHIEF OF NAVAL OPERATIONS WASHINGTON DC SEP 82 4/6

UNCLASSIFIED F/G 15/5 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD P001234

Nunn Amendment
by
CPT John C. Franks

I. History of Amendment.

The Selected Acquisition Reports (SAR's) were instituted in 1967 as a Department of Defense (DOD) internal management reporting system. In 1969 Congress started receiving a limited number of SAR's with Public Law 94-106 requiring quarterly DOD SAR submissions. The SAR's for 31 December 1980 registered a whopping $47.6 billion quarterly increase in the acquisition costs of the 50 defense major weapon systems. After this report was released, Senator Sam Nunn (D-GA) reportedly stood before Congress holding a copy of one SAR over his head, asking Congress what should be done about the skyrocketing weapon systems costs and the SAR's complexity which makes it virtually impossible to be read or understood by Congress. From this start, the Nunn Amendment evolved. The purpose of the Amendment has been expanded from the control of the weapon systems cost growth and the implementation of an understandable reporting system to Congress; to incorporate the involvement of top level defense managers in controlling costs, and finally the utilization of more realistic inflation indices by the Defense Department.

The Nunn Amendment is the name given to Section 917 of the FY 82 DOD Authorization Act passed in early December 1981. Under this Amendment there are two types of unit costs reported: the total program acquistion unit costs, and the current procurement unit costs. The unit costs are compared to the baseline unit costs as reported in the 31 March 1981 SAR's. For each quarter of FY 82, the Amendment requires the Program Managers (PM's) of the weapon systems which reported SAR's on 31 March 1981 to submit a quarterly unit cost report not later than the seventh day of the month following the close of the quarter to the appropriate Service Secretary. Additionally, a special unit cost report is required from the PM if there is 'reasonable cause to believe' a breach has been incurred in the weapon system at any time during any quarter of FY 82.

There are two possible levels of a breach. The first is at the Service Secretary level. This is incurred if a weapon system exceeds the unit cost of the 31 March 1981 baseline by more than 15 percent. The Service Secretary, who is responsible for determining whether an actual breach has occurred, is then required by law to report to Congress within 30 days after his determination of a breach. This report must include the following six items:

a. A statement of the reasons for the breach.

b. The identities of the responsible officers (military and civilian).

c. Corrective actions taken to control future cost growth.

d. Performance or schedule milestone changes which caused the breach.

e. The identities of the principal contractors involved.

f. An index of all Congressional testimony on the weapon system.

The second level of breach rests with the Secretary of Defense. This occurs if there is more than a 25 percent increase over the baseline. In addition to the submission of the Service Secretary, the Secretary of Defense must certify to Congress within 60 days of determination that:

a. The breached weapon system is essential to the national security.

b. There are no alternatives to the breached weapon system which will provide equal or greater military capability at less cost.

c. The new cost estimates are reasonable.

d. The management structure of the breached weapon system is adequate to manage and control costs.

Failure to provide either the report or certification to Congress on time automatically revokes the PM's authority to obligate funds for the breached weapon system. There is no provision in the Nunn Amendment to restart the funding process once either the late report or certification is provided to Congress.

II. Implementation.

The three services have implemented the Nunn Amendment in a similiar fashion. The Army and Navy are utilizing the same format in submitting the PM's input to the Secretariats. The Navy's SSN-688 Class Submarine's 31 March 1982 unit cost report is provided as an example. (Inclosure 1.) Although the Air Force utilized a different format, their content is identical to that illustrated.

The SAR's are required by Congress 30 days after the end of each fiscal quarter except for the 31 December SAR which is due 20 days after the President has submitted his budget. The Nunn Amendment unit cost reports are required on the seventh of the month following the end of each fiscal quarter. Both the SAR's and the quarterly unit cost reports should have identical costs. But, as has been the case in the past three quarters, all three services have met with time-phasing problems in data collection and assimilation for consistency between the two reports. Therefore, updated Nunn reports are often necessitated for the quarterly unit cost reports to agree with the final SAR's submitted.

III. Breaches.

During the first three quarters of FY 82, the three services reported 28 breaches (7-Army, 10-Navy and 11-Air Force) involving 21 weapon systems

(5-Army, 8-Navy and 8-Air Force). These 28 breaches were separated into two types: nine current procurement unit cost, and 19 program acquisition unit cost type of breaches. Seven were Service Secretary and 21 Secretary of Defense level breaches. It is possible to incur both a current procurement unit cost and a program acquisition unit cost breach for the same weapon system; and indeed, that situation has occurred within several systems. The table below provides a breakout of the levels and types of breaches incurred:

	Level of Breach					
	Army		Navy		Air Force	
Type	15%	25%	15%	25%	15%	25%
Current Procurement	0	3	1	2	0	3
Program Acquisition	0	4	2	5	4	4

The unit cost changes (cumulative percentage change from the 31 March 1981 SAR baseline) for the three services' major weapon systems are at Inclosures 2, 3 and 4. The Army and the Navy incurred all of their breaches in the first quarter and then remained fairly constant; whereas, the Air Force incurred two additional breaches during the second quarter and one in the third.

The Army's seven breaches occurred in five weapon systems. (Inclosure 2.) Accounting for four of the seven breaches are PERSHING II and APACHE; wherein, each breached both types of unit costs. This was caused primarily by low initial cost estimates compounded by the high rate of actual inflation. The other three Army breaches do not reflect upon the Army's cost management efforts. PATRIOT breached the total program acquisition unit cost primarily due to a change in the definition of the basic weapon. Initially, a PATRIOT fire unit included only 12 missiles; whereas, current doctrine dictates 32 missiles per fire unit. This increase in firepower requires additional launchers and missiles while the number of fire units remains constant. The HELLFIRE current procurement unit cost breach resulted from a November 1981 Congressional reduction without prejudicial language of FY 82 procurement funds by $15 million. Since the program is in the first year of production, the high ratio of fixed-to-variable costs forced the breach once the Congressional decrement was invoked. The ROLAND program acquisition unit cost breach was caused solely by the Army's September 1981 decision to terminate the program beyond FY 82.

For the Navy eight of the 23 major systems have unit cost increases greater than 15 percent with the SPARROW and SSN-688 Class Submarine breaching both types of unit costs. (Inclosure 3.) Of these eight breached weapon systems, one (the 5-inch Guided Projectile) was cancelled by the Secretary of the Navy. Six (SSN-688 Class Submarine; FFG-7 Guided Missile

Frigate; F-14A TOMCAT; PHOENIX; SIDEWINDER, and TRIDENT I missile) exhibited increases attributable to changes in the total program quantity. Increasing the quantity in the outyears appears as a unit cost increase; when in fact, it is the product of escalation compounded over many years. The one Navy program that has a valid unit cost increase is SPARROW. The SPARROW's cost growth stems from program restructuring dictated by difficulties encountered in transitioning from development to full production complicated by the Congressional cut of 320 missiles in FY 82.

The Air Force reported seven breaches in six weapon systems for the first quarter of FY 82. (Inclosure 4.) Only the SPARROW (for which the Navy is the lead service) breached both types of unit costs in this quarter. During the second quarter, ending 31 March 1982, both HARM (the Navy is also the lead service in this joint program) and the Ground Launched Cruise Missile (GLCM) programs breached the 15 percent level. Both the F-15 and F-16 breached the 25 percent level of the total program unit cost due to the inflated costs accentuated over many years by the procurement of additional aircraft and supporting equipment in the outyears. The A-10 exceeded the current procurement unit cost limit due to a decrease in the planned FY 82 aircraft procurement. The high ratio of fixed-to-variable costs forced the breach. The majority of the Defense Satellite Communication System (DSCS), GLCM, and MAVERICK's cost growth stems from low initial cost estimates; although, design and schedule changes contributed to the cost growth. HARM incurred an Air Force, but not a Navy breach. The cause of this breach is the slowdown by the Air Force from an aggressive build-up rate initially planned in March 1981 combined with the addition of a second source contractor. This provided for a higher production rate and completion of the required buy at an earlier timeframe. The Navy priced a very conservative build-up rate and thus incurred no breach.

IV. Future Amendments.

The Nunn Amendment as described above was a one year effort; however, Congress has made it clear they desire a continuing unit cost breach reporting effort. At one time there were five proposed Congressional Amendments for FY 83, three in the House and two in the Senate, which surfaced as possible Nunn successors. Highlights of these FY 83 Amendments as they differ from the present FY 82 Nunn Amendment are as follows:

a. McCurdy Amendment (House).

- Comprehensive SAR's are required annually, 30 days after the submission of the President's Budget to Congress. Abbreviated SAR's are required for each intervening calendar quarter if there has been a change in program cost, performance or schedule since the last report.

- All weapon systems are automatically included in SAR's as soon as the estimates by the Secretary of Defense exceed $200 million in RDT&E or $1 billion in Procurement (in FY 80 dollars).

- A breach reportable to the Service Secretary is also incurred if contract costs or schedule variances exceed 15 percent of the cost of the contract as of the time it was awarded. Additional reports will be submitted for each five percent incremental increase until the next annual SAR resets the baseline.

b. Emery Amendment (House).

- SAR's are required for all defense systems estimated to cost more than $200 million in RDT&E or $1 billion in Procurement.

- Reporting may be waived by majority vote in the House and Senate Armed Services Committee.

c. Hertel Amendment (House).

- The House version which combines all parts of the Nunn and Levin Senate Amendments, which are addressed below.

d. Nunn Amendment (Senate).

- Baselines are reset each year to the current estimate in the December SAR which reflects the President's Budget for the current FY (e.g., the December 1981 SAR reflects the FY 83 budget submission and will be used as the baseline during FY 83).

- Service Secretary is required to make the threshold breach determination within seven days and to inform Congress within ten days of receipt of the PM's notification of a possible breach.

e. Levin Amendment (Senate).

- Copies of the Service Secretary's report and the Secretary of the Defense's certification are to be submitted to the Government Accounting Office (GAO) and Congress, concurrently.

- GAO must then submit a report to Congress within 45 days stating the Comptroller General's opinion on the report or certification. The GAO report must also include a recommendation on the need for additional cost control efforts.

- These requirements do not apply to programs that breached due to cancellation.

As of mid-August 1982, the Senate passed both the Nunn and Levin Ammendments, and the House passed the McCurdy and Emery Amendments. In a joint committtee the House and Senate Conferences are deliberating the FY 83 DOD Authorization Bill and will address the future of unit cost reporting at that time.

The McCurdy Amendment appears attractive on the surface due to the annual comprehensive and quarterly abbreviated SAR's. A closer review of the McCurdy Amendment reveals a tremendous increase in the number of SAR's to be reported to Congress along with requirements for the PM's to report contract costs or schedule variances exceeding 15 percent to the Service Secretaries. These negative features far outweigh the benefits derived from an annual SAR. The new Nunn Ammendment would require revisions granting the Service Secretaries more time to make a breach determination. It also would include a provision authorizing re-obligation of funds if either a late report or certification is submitted to Congress. The Levin Amendment pertains more to the GAO than the Defense Department. Naturally, the Defense Department would prefer an environment without these reporting requirements. The next best alternative according to DOD would be the new Nunn Amendment with revisions, although the McCurdy Amendment with some alterations has support within DOD.

V. Summary.

As previousy mentioned the Nunn Amendment has four objectives of various scope. Of the four none has met with overwhelming success in the course of the past three quarters. The Nunn Amendment has apparently not been able to control costs in the short run, although more time would be necessary to see how effective the Amendment or its successor are in controlling costs over the long run. Secondly, the SAR's have not been revised into an understandable reporting system. Congress may well give up on the SAR's as currently structured and be forced in the future to rely on the Nunn Amendment or its successor for an understandable report. Thirdly, top level defense managers' involvement has been evident thus far; but in the future, the Nunn Amendment or its successor might just become another routine report which is delegated to subordinate levels. Although the Defense Department was allowed to use the Defense Market Basket rates in January 1982, there is still a long ways to go toward estimating realistic inflation indices.

The only valid observation which can be drawn from the Nunn Amendment thus far is that it will certainly continue for some years.

Report as of: 31 March 1982

UNIT COST REPORT (RCS DD-COMP(Q&AR) 1591

PROGRAM: SSN-688 Class Submarine

A. TOTAL PROGRAM ACQUISITION UNIT COST

	31 Mar 81 Baseline	Current Estimate	Difference +/-
Total Quantity:	44	56	+12
Total Cost in Escalated $:	$14,567.2	$24,266.1	+$9,698.9
Program Unit Cost in Escalated $:	331.073	433.323	+102.250
		Escalated $ Percentage Change:	+30.88%
Total Cost in Constant FY 71$:	$7,084.2	$9,203.1	+$2,116.9
Program Unit Cost in Constant $:	161.005	164.341	+3.336
		Constant $ Percentage Change:	+2.07%

B. CURRENT (FY 1982) PROCUREMENT UNIT COST

	31 Mar 81 Baseline	Current Estimate	Difference +/-
Procurement Appropriation(s): SCN			
FY 82 Procurement Quantity:	2	2	-
FY 82 Procurement Cost in Escalated $:	$1,396.6	$1,632.6	+$236.0
Procurement Unit Cost in Escalated $:	698.300	816.300	+118.000
		Escalated $ Percentage Change:	+16.9%

Inclosure 1

Inclosure 2

Army Unit Cost Changes
(Cumulative Percentage Change From Baseline)

	Current Procurement			Program Acquisition		
SYSTEM	31 Dec 81	31 Mar 82	30 Jun 82	31 Dec 81	31 Mar 82	30 Jun 82
PATRIOT	11.8	11.8	11.8	26.5*	33.9	33.6
PERSHING II	29.5*	29.6	29.6	56.8*	56.8	56.8
HELLFIRE	47.2*	47.2	47.2	-4.8	-4.8	-4.8
CH-47	1.3	1.7	1.7	3.9	3.9	3.9
BLACK HAWK	-2.6	1.7	1.9	7.2	5.7	6.0
APACHE	49.3*	49.2	49.2	48.4*	48.4	48.4
SOTAS	N/A	N/A	N/A	N/A	N/A	N/A
FVS	-6.0	-5.9	-5.9	13.8	13.8	13.8
M1	-6.5	-6.5	-6.5	5.4	5.3	5.0
ROLAND	N/A	N/A	N/A	143.0*	143.0	143.0
COPPERHEAD	-2.5	14.8	10.2	-13.7	1.8	2.4
DIVAD	3.2	3.2	3.2	-7.5	-5.4	-5.4
MLRS	0.3	0.3	0.3	-12.3	-12.3	-12.3
M-198	0	-0.3	-0.3	-0.2	1.0	1.0

* Secretary of Defense level breach

Inclosure 3

Navy Unit Cost Changes
(Cumulative Percentage Change from Baseline)

	Current Procurement			Program Acquisition		
SYSTEM	31 Dec 81	31 Mar 82	30 Jun 82	31 Dec 81	31 Mar 82	30 Jun 82
E-2C	0.3	0.3	-0.2	11.7	10.2	10.4
F-14A	2.0	2.3	2.5	79.0**	79.1	79.1
F/A-18	-2.0	-2.0	-2.3	12.5	12.5	12.5
P-3C	-7.1	-7.1	-9.0	11.9	11.9	11.8
LAMPS (A/C)	-5.7	-5.7	-7.3	13.2	13.2	12.9
LAMPS (Ship)	-0.2	-0.2	-0.2	3.8	3.8	3.8
CAPTOR	-0.2	-0.2	-0.2	1.6	1.6	1.6
HARM	13.3	13.3	13.3	5.9	5.9	5.9
HARPOON	10.0	10.0	9.8	9.2	9.2	9.1
PHEONIX	-3.0	-3.0	-3.0	18.8*	18.8	18.8
SIDEWINDER	34.5**	34.5	34.5	6.3	6.3	6.3
SPARROW	44.3**	44.3	43.7	31.9**	31.9	31.9
TOMAHAWK	-1.4	-1.4	-1.4	-27.2	-27.2	-31.7
TRIDENT (Ship)	N/A	N/A	N/A	10.7	10.7	10.7
TRIDENT (Msl)	-0.4	-0.4	-0.4	36.3**	35.0	35.0
5-inch GP	N/A	N/A	N/A	2,214.6**	2,214.6	2,214.6
SURTASS	-0.7	-0.7	-0.7	N/A	N/A	N/A
TACTAS	N/A	N/A	N/A	4.4	4.4	4.4
SSN-688	16.9*	16.9	16.9	30.9**	30.9	30.9
CG-47	1.7	1.7	1.7	9.0	9.0	9.0
FFG-7	-0.2	-0.2	-0.2	17.3*	17.3	16.9
PHM	N/A	N/A	N/A	2.5	2.5	2.5
CVN-71	N/A	N/A	N/A	1.5	1.5	1.5

* Secretary of the Navy level breach
** Secretary of Defense level breach

Inclosure 4

Air Force Unit Cost Changes
(Cumulative Percentage Change From Baseline)

	Current Procurement			Program Acquisition		
SYSTEM	31 Dec 81	31 Mar 82	30 Jun 82	31 Dec 81	31 Mar 82	30 Jun 82
A-10	28.0**	28.5	28.5	3.0	3.4	3.5
F-15	5.0	TBD	5.3	52.0**	TBD	44.2
F-16	8.4	10.8	10.8	38.4**	44.5	44.7
E-3A	4.0	2.2	2.2	3.0	7.2	7.2
E-4	N/A	N/A	N/A	-29.0	-29.3	-29.3
EF-111A	5.0	5.6	5.6	2.0	3.2	3.2
PLSS	N/A	N/A	N/A	12.0	-8.0	-0.2
IR MAVERICK	-1.0	-0.4	128.0**	16.2*	19.7	49.5**
HARM	0	14.0	11.5	1.0	21.6*	21.6
SIDEWINDER	0	-0.5	-1.2	-3.0	0.9	-0.3
SPARROW	41.7**	41.8	41.8	18.5*	27.3	27.3
DSCS III	0	1.4	1.4	37.0**	59.6	59.6
NAVSTAR	N/A	N/A	N/A	10.0	5.5	5.5
ALCM	0	-0.4	-0.4	7.0	11.6	14.1
GLCM	0	-0.4	-0.4	0	23.5*	19.9

* Secretary of the Air Force level breach
** Secretary of Defense level breach

AD P001235

PRICE COMPETITION BETWEEN MAJOR WEAPON SYSTEM CONTRACTORS

Dick Trainor

INTRODUCTION

One of the key functions of competition is to assure the cost of the product reflects the cost of an efficient production process plus an equitable mark up. Certainly with the high cost of modern weaponry there are strong incentives to increasing the emphasis on competition for major weapon system contracts as a means of assuring the taxpayers they are getting their money's worth.

In fact, increased use of competition is, and has been, the backbone of Department of Defense policy for many years. This policy is fully endorsed by Congress, and DoD is continually urged to place even greater emphasis on competition as a means of controlling and reducing weapon system cost. Yet, not much happens. It is difficult to recall a major weapon system where competitive procurement has been a key feature of the program. A few small missiles (SIDEWINDER, DRAGON, SPARROW, TOW) come to mind. However, price competition during the procurement phase has been restricted mainly to items such as trucks, ammunition, radios and black box subsystems. Certainly major systems such as the F-15, F-16, AWACS, MINUTEMAN, HARPOON, S-3A, POLARIS, TRIDENT, M-1, M-2/3 are all costly, but have not enjoyed the benefits of competition.

The remainder of this paper will examine the major disparity between the policy and the practice. The reasons for the disparity will be addressed and an assessment made as to whether the practice should be (and can be) realigned to match the policy, or vice versa -- or whether it really matters in the first place.

TRENDS IN KEY VARIABLES

Competition can be achieved in more than one manner, can be achieved at various organizational levels and can have objectives other than cost control/reduction. For example, competition during the early stages of development can result in different and innovative technological approaches to a common problem or mission. These benefits are quite meaningful, but are not attained by price competition. This paper will address only the economic aspect of competition for major systems and only at the prime contractor level. At that level there are several key variables, which in composite, will determine the magnitude of any reduction in cost attributable to competiton.

The following paragraphs identify the key variables and the manner in which they have changed in the past 10-20 years.

1. Production Rate

Economic benefits are most easily attained if high rates of production can be achieved. However, production rates for virtually all classes of weapon systems have been drastically reduced in comparison to rates that were common 20 or so years ago.

2. Duration of Stable Production Period

Economic benefits of competition require that the system be produced for at least a five year period and preferably over eight or more years. (The long time period relates mainly to variables 4 and 5.) The duration of the production cycle has not changed appreciably over time. However, the rate of production has not remained stable. Instead the rates of production on many systems have been altered year by year, often being reduced as a means of accommodating unit cost growth.

3. Production Quantity

If factors 1 and 2 are considered jointly they obviously imply that large production quantities are required for economical second sourcing.[1] However, production quantities during the past 10-20 years have been reduced, often drastically, for nearly all classes of systems.

4. Time Required to Stabilize Design

Production by the second source requires that the development process be essentially complete and engineering/production changes have dropped to a modest level. However, as a consequence of increased weapon system complexity and increased emphasis on operational testing, the design of today's weapon systems requires more time to stabilize.

5. Time to Qualify Second Source

The benefits of competition will be maximized if the time required to validate the second source's production line is small in comparison to the total period of production. As a corollary,

1/ In this paper the second source is assumed to compete wth the developer/initial producer on a winner-take-all basis after an initial learning contract.

the number of units produced by both contractors prior to validation of the second source's production line should represent a small percent of the total production quantity. Unfortunately, as a consequence of greatly increased production lead times in recent years the time to qualify the second source has increased substantially from the time required 10-20 years ago.

6. Learning Curve Slopes

Competition is more likely to be beneficial if the nature of the product and production process lends itself to steep learning curves. (Given that steep learning slopes are possible, it is also necessary that the prime contractor be an inefficient producer, i.e., he is attaining learning slopes that are flatter than are possible for an efficient producer.) However, today's learning slopes are relatively flat, often in the range of 85-90% compared to the 80-87% range common in the 1950s and early 1960s. The flatter slopes are largely the result of a higher degree of automation in production and the higher electronic content of todays's weapon systems.

7. Rate-Cost Sensitivity

There is now mounting evidence of diseconomies associated with producing systems at low rates. Some analysts feel that reducing the production rate by half will increase production recurring unit costs by 10-15 percent. Yet an inherent penalty of second source production competition is that a higher percent of the total items will be produced at lower, less economical rates.

8. Nonrecurring/Recurring Cost Ratios

The economic benefits of competition occur only during the recurring production phase of the program. Therefore, net economic benefits will be maximized when nonrecurring production costs are small in comparison to recurring costs. However, in the last 10-20 years nonrecurring production costs have increased markedly in relationship to recurring costs. This increased ratio has been caused by increased weapon system complexity, and increased use of automation in production and acceptance testing as well as the reduced number of production units, discussed previously.

9. Value Added

Economic benefits of competition at the prime contractor level requires that value added by the prime contractor be large in comparison to the value of subcontracts. Due to the higher electronic and electro-mechanical content of modern weapon systems (subsystems in these categories are often subcontracted) the

value added by the prime contractor is usually less today than 10-20 years ago. Final assembly is invariably performed by the prime contractor, but today this function often constitutes as little as 25 percent of the total recurring unit cost.

10. Facility and Worker Availability

Competition is likely to be most beneficial when the desired production rates overtax the facilities and the existing production work force of the prime contractor. However, the aerospace industry is characterized by an over abundance of general purpose facilities, tools and workers of low and medium skill levels.

11. Special Production Skills/Facilities

It is easier to establish a second production source if the need for specialized production skills and facilities are minimal. However, most modern weapon systems require specialized production techniques to enable the system to achieve its performance and reliability goals. Typically there are intermittent shortages of special purpose facilities and of highly skilled production workers. These shortages are caused by the unique production skill requirements of individual weapon systems coupled with low profit margins and high interest rates which prevent many companies from purchasing modern equipment.

12. Unique Production Processes

It is easier to establish a second source if the production drawings are available from the prime contractor and compatible with the production processes used by the potential second source. Most companies do utilize production processes that are quite similar for common systems and for comparable production rates. However, companies almost invariably have some unique production processes and their existence inhibits intercompany technology transfer.

13. Proprietary Data Rights

It is difficult to establish a second source if the developer/prime contractor retains proprietary data rights to key weapon system features. Negotiating for a technical data package in a sole source environment can be expected to be time consuming and often unproductive. Today's weapon systems are larger, more complex and their production is more likely to involve proprietary data. These problems are solveable but the solutions involve careful planning and agreements made at program inception. Government planners have become more adroit in recent years at causing companies to give up proprietary data rights as the price

of entry into the competitive process. The net long term gain of this practice is questionable, in that it inhibits innovation and free exchange of information with government employees.

14. Availability of Other Cost Reduction Incentives

Competition at the prime contractor level is most likely to yield substantial reductions in unit cost if the prime contractor has few incentives other than the threat of competition to cause him to produce efficiently. Through the years managers in the Department of Defense have experimented with a variety of techniques to reduce costs. These have varied from total package procurement to the concept of design to cost. Overall, the ability of Department of Defense managers to incentivize the aerospace industry to maximize production efficiency has not changed appreciably through the years.

ASSESSMENT

Review of the 14 variables discussed in the previous paragraphs leads to a simple and clear cut conclusion. Competition at the prime contractor level for major weapon systems for purposes of net cost savings is substantially less plausible than was the case 10-20 years ago. Further, the track record of competition for purposes of cost savings 10-20 years ago was not very good. There are very few instances where clear economic benefits can be shown even in those decades when the environment was much more conducive to savings through price competition.

BASIS FOR CURRENT POLICY

The previous paragraphs make the case that the Department of Defense policy endorsing competition is not viable. In the main it will cost money, due to the high nonrecurring costs associated with establishing the second source. This assertion leads to two rhetorical questions. The first, "Why does the policy exist if it is not logical?" The second question is, "Is there a better way?"

Addressing the first of the two questions, there appear to be 6 categories of reasons for the current policy. These are:

Tradition and Politics

Traditionally, American industry has thrived on competition. In the absence of definitive evidence it has been assumed that what is good for America, in general, can also be beneficially applied to the aerospace industry. This line of reasoning is intuitively acceptable to the law makers and is understandable to their constituents. Further it is consistent with the views

of Congress that competition represents an equitable means of geographically distributing aerospace contracts.[1]

Absence of Definitive Studies

There has not been a truly definitive, comprehensive study of the aerospace industry since the 1959-1960 period. The "Weapons Acquisition Process" was the last study with the sufficient depth and breadth to provide a basis for challenging or validating the assertions in this paper.[2] The value of a new comprehensive study of the industry would extend well beyond the study of the policy on competition.

Misused Analysis

Quantifying the economic benefits of competition is inherently difficult. Precision is impossible due to the many variables that cannot be quantified. Analysts that attempt quantification are put in the position of predicting, "what would have happened, if". Still, analyses have been made and in general provide a reasonable basis to support price competition for the types of items analyzed. The 1978 Army study[3] and the 1979 IDA study[4] were probably the two best efforts that tried to establish the magnitude of dollar savings. These studies analyzed electronic subsystems, items of ammunition but very few weapon systems. For example, the average unit cost in the 16 Army case histories was $14,525 in 1972 dollars. (The average cost, excluding the three highest cost items was $4,950.) The 1979 IDA summarized the data bases from three prior studies. In all, they considered fifty five cases. Forty eight of the fifty five items had unit costs that ranged from $4,100 to $8,400 in 1980 costs. One ship, one medium size missile and one small helicopter were the only systems that had unit costs that allow them to be classified as major weapon systems. (Small missiles are a special case to be discussed next.)

1/ "Competition in the Acquisition of Major Weapon Systems: Legislative Perspectives", RAND Report R-2058-PR, November 1976.

2/ The Weapons Acquisition Process, An Economic Analysis, Morton J. Peck and Frederic M. Scherer, Harvard University, 1962.

3/ "Determining and Forecasting Savings From Competing Previously Sole Source/Noncompetitive Contracts", Army Procurement Research Office, October 1978.

4/ "The Effect of Price Competition in Weapon System Acquisition Costs", IDA Paper P-1435, Institute for Defense Analyses, September, 1979.

Yet these studies provide the analytical basis, to the extent that one exists, for the present policy on price competition. These studies simply do not provide a logical basis for the current policy unless one is willing to assume that the acquisition variables that predestine the economics for small end items and subassemblies are the same as those that affect major weapon systems. This would be a most heroic assumption.

Extrapolations From Small, Simple Missiles

Through the years, some small missiles (SIDEWINDER, SPARROW, TOW, DRAGON, SHILLELAGH) have been competed. It is likely that on the DRAGON program the net cost to the government was reduced. However, there is room for argument even for this system. These systems are characterized by their simplicity, high production rates, large quantities and relatively low nonrecurring to recurring cost ratios -- all characteristics which favor competition. Because these items are called weapon systems, policy makers use them as examples of cost savings achievable through competition. They are even the basis for the old wives tale that competition will reduce costs by 25 percent. This assertion cannot be fully supported for even one of these small missiles, much less for complex weapon systems.

Faulty PPBS System

The planning, programming, budgeting system in the Department of Defense has many virtues and these are widely recognized. One major fault of the system is that it allows and incentivizes the military departments to initiate more major weapon systems than can be produced at economical rates. Consequently, policy makers often believe competition will be beneficial based on review of planned rates/quantities in the Five Year Defense Plan and the Extended Planning Annex. Later, as vast plans change to budget realities the actual rates and quantities are often very different, with most of the adjustments being downward.

Assumed Collateral Benefits

Many have recognized the shaky logical foundation for assuming that price competition will provide net economic benefits. Some sceptics use the argument that since other cost control mechanisms do not seem to be effective, imposing the threat of competition will cause the prime contractor to operate more efficiently and with modest profit margins. There is merit to this line of reasoning but here again there is no free lunch. The threat cannot be maintained without occasionally carrying through the process. Further, the prime contractor cannot be expected to invest in equipment to enhance production efficiency if he does not have the expectation of enough production to amortize the

equipment cost. Perhaps of greater importance is that the maintenance of a policy of price competition reduces management interest in other policies that have a much higher likelihood of economic benefit. These policies will be discussed next.

POLICIES THAT ARE MORE APPROPRIATE

The following four policies should be emphasized as a means of controlling and reducing costs of major weapon systems. These policies should be emphasized in lieu of the current inordinate emphasis on price competition at the prime contractor level.

More Virtual Competition

The most effective and cost effective competition is the threat to the new developer/producer from the currently fielded system. The threat of product improvement of the fielded system versus new production is termed virtual competition. This form of competition is normal, inexpensive and can be extremely effective. It deserves much more emphasis. Full implementation will require that weapon systems be designed with even greater growth potential than is presently the case.

A fundamental requirement of virtual competition is that the producer of the fielded system not be the producer of its complement or replacement. For example, you cannot have effective virtual competition if Chrysler builds the M-60 and M-1 tank, if FMC builds the M-113 personnel carrier and the M-2/3 series or if Raytheon builds the Improved HAWK and PATRIOT missiles. Accordingly, companies should effectively be prevented from bidding if the award would give them a monopoly in an important mission area. On the other hand, in many military product areas there is no need for an exclusionary policy. For example, McDonnell Douglas produced the F-4 and is producing its successor, the F-15 and also the F-18. In this product area General Dynamics (F-16), Grumman (F-14) and Northrop (F-5 and a major subcontractor on the F-18) represent sufficient threats to guarantee reasonable efficiency by McDonnell Douglas.

Competition at Subcontract Level

Since the value added for major weapon systems is increasingly at the subsystem level, competition should also be focused at that level. The government's role should be to provide guidance and funding to assure there are alternate suppliers for commonly used and expensive weapon subsystems. In some cases where there are clear technical interfaces, the government may wish to establish a policy of directed subcontractors. However, the selection of subcontractors normally should be left to the prime contractor with policy guidance provided by the government program manager.

More Emphasis on Breakout

After the first two-three years production of a well managed program that has attained design stability, the integration of certain subsystems involves little more than routine acceptance testing by the prime contractor and assembly as a part of the weapon system. Even though the process has become routine the prime contractor can sometime negotiate a contract incommensurate with his value added. The best policy to combat this profit pyramiding is to break out the subcontracted assemblies with the government providing the assemblies to the prime contractor as government furnished equipment. If breakout is to be effective, the design must be stabilized and the technical interfaces must be clearly established.

More Equitable Contracts

The old rule in the aerospace industry was to perform research and development at cost, make money in production and make larger profits (sometime excessive profits) on the sale of followon spares. This policy worked with reasonable equity as long as development costs were relatively small in relationship to production costs. However, this is no longer the situation. In the last five years the military departments have forced increasing use of fixed price contracts for high technology developments. The result has been government inducement of major corporations to help fund the front end, implicitly in exchange for the later production of end items. This policy is shortsighted and represents government encouragement of "buying in". If the developments are of medium or high risk, cost growth is inevitable and the companies involved stand to lose money on these contracts.

The government should fully fund development contracts, using cost plus incentive fees/award fees for virtually all development contracts. On the other hand, the government should strengthen its ability to negotiate tough but fair procurement contracts once the design has stabilized. Usually this can be in the form of firm fixed price contracts. Implementation of this policy will require the government to improve the quality of its cost analysis personnel and of its negotiators.

SUMMARY

This paper has addressed the subject of price competition for major weapon systems at the prime contractor level. It has been shown that most of the 14 variables that determine the economic benefits of price competition have changed over the last 10-20 years. They have changed in a direction that opposes competition as a useful way of reducing and controlling the cost of

major systems. The nonrecurring costs associated with establishing a second source are typically greater than the recurring costs that can be saved through competition. Still the policy lingers on, in spite of its lack of viability. The paper has offered reasons for this inconsistency between policy and practice. More importantly, alternatives are offered which, if emphasized, will help control and reduce system costs. These include use of virtual competition, competition at the subcontractor level, breakout and more appropriate contract forms.

It should be emphasized that this paper supports the use of competition. Competition, appropriately used, can promote innovation and in most cases can assist in cost control. It just happens that price competition at the prime contractor level for major systems is an exception to that rule. It is time we recognized the exception and get on with other means of cost control and reduction.

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PRODUCTION RATE ADJUSTMENT FACTORS (PRAF) COST MODEL

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The AVRADCOM Directorate for Plans and Analysis developed an investment model that provides quick reaction "time-phased" cost estimates. It incorporates the "learning curve" lot size technique and Production Rate Adjustment Factors (PRAF) to calculate "adjusted average lot costs" by year. The PRAF's are results of complicated mathematical equations; their main assumptions are that the "average unit cost" increases whenever the lot size is varied. This program also stratifies the total investment costs by partial "work breakdown structure".

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1. INTRODUCTION

The AVRADCOM Directorate for Plans and Analysis developed an investment cost model that provides quick reaction "time phased" cost estimates. It incorporates the "learning curve" lot size technique and Production Rate Adjustment Factors (PRAF) to calculate "adjusted average lot costs" by year. The PRAFs are results of complicated mathematical equations; their assumption is that the "average unit cost" increases whenever the lot size is varied.

This program also stratifies the total investment costs by partial "work break-down structure" and by year.

2. MODEL DESCRIPTION

2.1 MODEL METHODOLOGY

This Production Rate Adjustment Factors (PRAF) Cost program employs two specialized estimating methodologies; learning curve theory and PRAF techniques.

2.1.1 LEARNING CURVE THEORY

Learning curve theory, simply stated, says that the cost to produce the "next" item is less expensive than the previous item. This phenomenon happens because the producer literally "learns" better production methods as he is producing the items.

The PRAF model makes use of the learning curve methodology by extracting the following information from a previous lot of the same type of items under analysis (for instance, U.S. Army Helicopters): He selects a learning curve slope, which can range from 1. to 0. (More accurately, he uses the commonly accepted slope for the item in question.). A slope of '1' means there is no learning; a '0' indicates perfect learning (the second item would then have a zero procurement cost). The user then extracts the production numbers of both the "first unit" and "last unit" in the Lot. For example, if the first Lot had 10 units and the second Lot has 15 units, the first and last units of Lot #2 are 11 and 25 respectively. The user finally calculates the "average unit cost of the lot" by dividing the known total Lot cost by the number of units in the Lot.

The model, itself, then calculates "A", the First Unit Cost in the following manner;

$$B = \frac{\log\ (\text{SLOPE})}{\log\ (2)} = \text{learning curve parameter}$$

M = Average unit cost of the Lot

Q_1 = First unit of Lot

Q_2 = Last unit of Lot

A = First Unit Cost

$$A = \frac{M\,(Q_2 - (Q_1 - 1))}{Q_2^{B+1} - (Q_1 - 1)^{B+1}}$$

The First Unit Cost (this is, the first unit of first Lot) can then be used to help determine the cost of any subsequent Lot;

B = learning curve parameter

A = first unit cost (of first Lot)

F = first unit of given Lot

L = last unit of given Lot

AUC = Cost of average unit in given Lot

$$AUC = \frac{A(L)^{B+1} - A(F-1)^{B+1}}{L-(F-1)}$$

AUC determines the "average unit cost" for any Lot. However, the PRAF theory states; when the production rate varies among Lots, the 'average unit cost' will increase.

2.1.2 PRAF TECHNIQUES

The 'adjusted unit cost' will always increase as the production rate is either increased or decreased. The underlying rationale is that the learning process regresses due to a variation in the procedure.

There are 3 PRAF production efficiency rates (X, Y, Z). Common values are (8, 5, 3); however, these parameters can be modified. (A lengthy discussion on ideal PRAF values is beyond the scope of this paper.)

The 3 PRAF parameters are calculated;

$$P1 = \frac{\log \frac{100-X}{100}}{\log(2)}$$

$$P2 = \frac{\log \frac{100+Y}{100}}{\log(2)}$$

$$P3 = \frac{\log \frac{100-Z}{100}}{\log(2)}$$

The actual PRAF factor for a given Lot is;

$$PRAF = \left(\frac{\text{CURRENT YEAR QTY.}}{\text{BASE YEAR QTY.}}\right)^{P1} \times \left(\frac{\text{CURRENT YEAR QTY.}}{\text{PRIOR YEAR QTY.}}\right)^{PX}$$

where,

$$PX = P2 \text{ if } \frac{\text{CURRENT YEAR QTY}}{\text{PRIOR YEAR QTY}} \geq 1$$

and

$$PX = P3 \text{ if } \frac{\text{CURRENT YEAR QTY}}{\text{PRIOR YEAR QTY}} < 1$$

The 'adjusted unit cost' is also calculated;

Adjusted Unit Cost = PRAF X (Average Unit Cost)

2.2 MODEL INPUTS

PRAF is an interactive model; the user sits at a computer terminal, initiates the program, and answers the questions which are displayed.

Figure 2.1 gives a sample of the first phase of the PRAF model inputs.

The program first identifies itself. It then asks the user to type in the "Base Year Quantity" and "Prior Year Quantity". These Lot size values are needed to help determine the PRAF factors. (All variables must be separated by at least 1 space; decimal values are acceptable but not necessary.)

Figure 2.1 shows that the next inputs are the 3 Production Efficiency Rates. As previously stated, the standard values are (8, 5, 3). However, the user is free to input any values he deems appropriate.

The fiscal year of the first procurement Lot under analysis is the next number that the computer requests.

The advance procurement input section follows. Some long lead time parts must be purchased in the previous year to be available when needed. The computer asks: What percent of the current years gross Weapon System cost was required in the prior year's Advance Procurement? This cost will be deducted from the current year and added the prior year. The model adds flexibility by allowing the user to input (in constant dollars) the prior year Advance Procurement for the first Lot under consideration.

The next input group is designed to allow the computer to calculate the "First Unit Cost" (See Section 2.1.1). The slope, first unit, last unit, and average unit cost of a Lot (whose cost is known) are given to the model.

The final part of the first PRAF input phase asks the user to tell the number of Lots that will be costed in the current analysis. The maximum number is 30 Lots.

```
EXECUTION BEGINS...

THIS PROGRAM CALCULATES AVERAGE UNIT COST ACCORDING TO LOG LINEAR CUM-AVERAGE CURVES

INPUT PRAF DATA SPECIFIED BELOW IN ORDER GIVEN WITH SPACE BETWEEN NUMBERS:
    BASE YEAR QUANTITY
    PRIOR YEAR QUANTITY

 84   90

INPUT THE 3 PRODUCTION EFFICIENCY RATES (EXAMPLE -- 8 5 3)

 8   5   3

INPUT FISCAL YEAR OF FIRST PROCUREMENT LOTS  (4 DIGITS)

 1983

INPUT DATA SPECIFIED BELOW FOR ADVANCE PROCUREMENT COSTS:
    % OF NEXT YEARS GROSS WEAPON SYSTEM REQUIRED FOR ADVANCE PROCUREMENT (DECIMAL)
    PRIOR YEAR ADVANCE PROCUREMENT FOR LOT #1  (CURRENT YEAR $ IN MILLIONS)

 .10   2.00

INPUT DATA SPECIFIED BELOW IN ORDER GIVEN WITH SPACE BETWEEN NUMBERS:
    SLOPE OF CURVE (DECIMAL)
    FIRST UNIT OF BASE LOT
    LAST UNIT OF BASE LOT
    AVERAGE UNIT COST OF THE LOT  (CONSTANT $ IN MILLIONS)

 .9   37   120   2.00

INPUT NUMBER OF LOTS TO BE CALCULATED (MAX 30)

 3
```

Figure 2.1

The second phase of the input defines the characteristics of the various Lots (See Figure 2.2). The "Lot Escalation Factor" allows the "Work Breakdown Structure" (WBS) part of the PRAF report to be expressed in escalated dollars . The "first unit in Lot" and "last unit in Lot" (along with the previously determined A and B parameters of Section 2.1.1) give the computer sufficient information to calculate the "average unit cost" for each lot. The "Number of Costed Units in Lot" gives the number of units that apply to the project under consideration. Some units may be requisitioned by other agencies. The total Lot cost is the joint multiplication of "average unit cost", "PRAF factor", and "Number of Costed Units". The "Cost for Initial Spares" (in constant dollars) is tacked on for analysis in the WBS section of the output report.

INPUT FOLLOWING FOR EACH LOT:
- LOT ESCALATION FACTOR
- FIRST UNIT IN LOT
- LAST UNIT IN LOT
- NUMBER OF COSTED UNITS IN LOT
- COST FOR INITIAL SPARES (CONSTANT $ IN MILLIONS)

DATA FOR LOT 1				
1.00	211	294	84	1.00
DATA FOR LOT 2				
1.10	295	390	90	1.00
DATA FOR LOT 3				
1.20	391	486	90	1.00

Figure 2.2

2.3 MODEL REPORTS

Figure 2.3 shows the entire PRAF report.

A and B (the computer calculated learning curve parameters) are first displayed. The cost of the 'Nth' item is:

$$Cost(N) = A \times N^{B}$$

The cost figures of the various Lots are next displayed. The first and last units of each Lot (and the curve parameters) determine the "Average Unit Cost". (See Sector 2.1.1.) The PRAF factor was calculated according to the mathematics of Section 2.1.2. The "Adjusted Unit Cost" results from the multiplication of the "Average Unit Cost" with the PRAF. And the "Total Cost" equals the "Units Costed" times the "Adjusted Unit Cost".

The "Procurement Cost Summary" is the final part of the PRAF report. The columns stratify the costs by Fiscal Year (FY). The Five Year Development Plan (FYDP) contains the costs of the first 5 FYs. The CTC column has the total costs of the outlying years. And the right-most column shows the ground total cost.

The first row shows the FY. The second row gives the Lot quantity (Units Costed). The third row supplies the Gross Weapon System Cost. The Gross WS is identical to the inflated "Total Cost" in the first part of the PRAF report. The "Prior Advanced Procurement" is subtracted from the given FY and is added to the previous FY as "Current Advanced Procurement". The "Initial Spares" are then added to the adjusted "Weapon System Cost" to produce the finalized PRAF Procurement Costs.

CURVE INFORMATION: B = -0.15200311, A = 4.531

FIRST UNIT	LAST UNIT	LOT SIZE	UNITS COSTED	AVERAGE UNIT COST	PROD. RATE ADJUSTMENT	ADJUSTED UNIT COST	TOTAL COST (UNITS COSTED)
211	294	84	84	1.659	1.00303650	1.664	139.792
295	390	96	90	1.584	0.99335814	1.573	141.570
391	486	96	90	1.525	0.98406535	1.500	135.039

Figure 2.3

*** PROCUREMENT COST SUMMARY ***
CURRENT $ IN MILLIONS

FISCAL YEAR	FY 1983	FY 1984	FY 1985	FYDP ****	CTC ****	TOTL ****
UNITS COSTED	84	90	90	264	0	264
LOT COST	139.792	155.727	162.047	457.565	0.0	457.565
LESS PRIOR AP	2.000	15.573	16.205	33.777	0.0	33.777
LOT COST	137.792	140.154	145.842	423.788	0.0	423.788
PLUS CURRENT AP	15.573	16.205	0.0	31.777	0.0	31.777
LOT COST	153.365	156.359	145.842	455.565	0.0	455.565
INITIAL SPARES	1.000	1.100	1.200	3.300	0.0	3.300
PROCUREMENT	154.365	157.459	147.042	458.865	0.0	458.865

3. OVERVIEW

The coding of this model resides on a permanent disk pack in the Mid-West Scientific and Engineering (S&E) I.B.M. Computer System. (Appendix A shows the computer listing of the PRAF Model.). An explanation of most computer model symbols is given in Appendix B.

The model is executed directly by the "Time Sharing Option (TSO) system. The TSO user logs onto the computer, furnishes his password, then types -- CALL 'LAVBCAA.FAUC2.LOAD'. The program will begin executing. It will prompt the user to insert the proper input data, process these data, and print the PRAF report.

APPENDIX A

Computer Listing of PRAF Model

```
C
C
C
      REAL AUC(33), PRAF(33),TCOST(33),SPARI(33),PROC(33)
      INTEGER FUN(33),LUN(33),RFU,RLU,UNITS(33),PYQ,BYQ,UNC(33)
      DIMENSION IFY(33),GWS(33),APC(33),APP(33),ANWS(33),WS(33)
      DIMENSION APA(33), NAME(33)
      DATA IYES/'YES '/
      DATA IBLNK/' FY '/, IFYDP/'FYDP'/, ICTC/' CTC'/,
     *ITOT/'TOTL'/
   10 CONTINUE
      DO 3344 I=1,33
 3344 NAME(I)=IBLNK
      DO 888 N=1,33
      UNC(N)=0.
      GWS(N)=0.
      APP(N)=0.
      ANWS(N)=0.
      APC(N)=0.
      WS(N)=0.
      SPARI(N)=0.
  888 PROC(N)=0.
      WRITE(6,999)
      WRITE(6,990)
      READ(5,*) BYQ,PYQ
      WRITE(6,985)
      READ(5,*)  EXPA,EXPB,EXPC
      EXPA = ALOG((100. - EXPA)/100.)/ALOG(2.)
      EXPB = ALOG((100. + EXPB)/100.)/ALOG(2.)
      EXPC = ALOG((100. - EXPC)/100.)/ALOG(2.)
      WRITE(6,987)
      READ(5,*) IBFY
      WRITE(6,986)
      READ(5,*)PAP,PYAP
      WRITE(6,998)
      READ(5,*)SLOPE,RFU,RLU,RAUC
      WRITE(6,997)
      READ(5,*)NLOTS
      WRITE(6,996)
      DO 50 I=1,NLOTS
      WRITE(6,995) I
      READ(5,*) APA(I),FUN(I),LUN(I),UNC(I),SPARI(I)
      SPARI(I)=SPARI(I)*APA(I)
   50 CONTINUE
      B=ALOG(SLOPE)/ALOG(2.)+1.
      RFU=RFU-1
      A=RAUC*(RLU-RFU)/(RLU**B-RFU**B)
      DO 100 I=1,NLOTS
      UNITS(I)=LUN(I)-FUN(I)+1
      AUC(I)=(LUN(I)**B-(FUN(I)-1)**B)*A/UNITS(I)
```

```
C      COVRP=UNITS(I)/PYQ
       AAA=UNITS(I)
       BBB=PYQ
       COVRP=AAA/BBB
       PEXP=EXPC
       IF(COVRP.GE.1.)PEXP=EXPB
       CCC=BYQ
       COVRB=AAA/CCC
       PRAF(I)=COVRB**(EXPA)*(COVRP)**PEXP
       TCOST(I)=AUC(I)*PRAF(I)*UNC(I)
  100  PYQ=UNITS(I)
       WRITE(6,994)
       READ(5,909) KK
       B=B-1
       WRITE(6,993)B,A
       WRITE(6,992)
       DO 150 I=1,NLOTS
       ADJUC = AUC(I)*PRAF(I)
  150  WRITE(6,991) FUN(I),LUN(I),UNITS(I),UNC(I),AUC(I),PRAF(I),
      *ADJUC,TCOST(I)
       GWS(NLOTS+1)=0.0
       APP(1)=PYAP
       DO 300 I=1,NLOTS
  300  GWS(I)=TCOST(I)*APA(I)
       DO 301 I=1,NLOTS
       IFY(I)=IBFY+I-1
       APC(I)=GWS(I+1)*PAP
       IF(I.NE.1) APP(I)=GWS(I)*PAP
       ANWS(I)=GWS(I)-APP(I)
       WS(I)=ANWS(I)+APC(I)
  301  PROC(I)=WS(I)+SPARI(I)
       N=NLOTS+3
       NAME(NLOTS+1)=IFYDP
       NAME(NLOTS+2)=ICTC
       NAME(NLOTS+3)=ITOT
       DO 3002 IK=1,3
       IF(IK.EQ.1) IXX=1
       IF(IK.EQ.1) IYY=MINO(5,NLOTS)
       IF(IK.EQ.2) IXX=6
       IF(IK.EQ.2) IYY=NLOTS
       IF(IK.EQ.3) IXX=1
       IF(IK.EQ.3) IYY=NLOTS
       DO 302 I=IXX,IYY
       IF(IYY.LT.IXX) GO TO 302
       UNC(NLOTS+IK)=UNC(NLOTS+IK)+UNC(I)
       GWS(NLOTS+IK)=GWS(NLOTS+IK)+GWS(I)
       APP(NLOTS+IK)=APP(NLOTS+IK)+APP(I)
       ANWS(NLOTS+IK)=ANWS(NLOTS+IK)+ANWS(I)
       APC(NLOTS+IK)=APC(NLOTS+IK)+APC(I)
       WS(NLOTS+IK)=WS(NLOTS+IK)+WS(I)
```

```
      SPARI(NLOTS+IK)=SPARI(NLOTS+IK)+SPARI(I)
  302 PROC(NLOTS+IK)=PROC(NLOTS+IK)+PROC(I)
      IFY(NLOTS+IK)=99999999
      IE=0
 3002 CONTINUE
      JJ=-1
  810 JJ=JJ+1
      IF(IE.EQ.N) GO TO 800
      IS=1+9*JJ
      IE=9+9*JJ
      IF(IE.GT.N) IE=N
      WRITE(6,994)
      READ(5,909) KK
      IF(JJ.EQ.0) WRITE(6,900)
      WRITE(6,1899) (NAME(I),I=IS,IE)
      WRITE(6,899) (IFY(I),I=IS,IE)
      WRITE(6,898) (UNC(I),I=IS,IE)
      WRITE(6,897) (GWS(I),I=IS,IE)
      WRITE(6,896) (APP(I),I=IS,IE)
      WRITE(6,895) (ANWS(I),I=IS,IE)
      WRITE(6,894) (APC(I),I=IS,IE)
      WRITE(6,893) (WS(I),I=IS,IE)
      WRITE(6,892) (SPARI(I),I=IS,IE)
      WRITE(6,891) (PROC(I),I=IS,IE)
      GO TO 810
  800 CONTINUE
      WRITE(6,994)
      READ(5,909) KK
      WRITE(6,989)
      READ(5,908) I
      IF(I.EQ.IYES)GO TO 10
 1000 STOP
  999 FORMAT(//' THIS PROGRAM CALCULATES AVERAGE UNIT COST ACC',
     *'ORDING TO LOG LINEAR CUM-AVERAGE CURVES'//)
  998 FORMAT(/' INPUT DATA SPECIFIED BELOW IN ORDER GIVEN',
     *' WITH SPACE BETWEEN NUMBERS:'/'     SLOPE OF CURVE',
     *' (DECIMAL)'/'     FIRST UNIT OF BASE LOT',
     *' '/'     LAST UNIT OF BASE LOT',
     *' '/'     AVERAGE UNIT COST OF THE LOT',
     *'  (CONSTANT $ IN MILLIONS)'/)
  997 FORMAT(/' INPUT NUMBER OF LOTS TO BE CALCULATED (MAX 30)'/)
  996 FORMAT(/' INPUT FOLLOWING FOR EACH LOT:'/
     *'     LOT ESCALATION FACTOR'/'     FIRST UNIT',
     *' IN LOT'/'     LAST UNIT IN LOT'/'     NUMBER OF COSTED',
     *' UNITS IN LOT'/'     COST FOR INITIAL SPARES',
     *'  (CONSTANT $ IN MILLIONS)'/)
  995 FORMAT(' DATA FOR LOT ',I2)
  994 FORMAT(/' .')
  993 FORMAT(' CURVE INFORMATION:  B = ',F11.8,', A = ',F10.3///)
  992 FORMAT('     FIRST      LAST       LOT     UNITS',
```

```
     *'          AVERAGE          PROD. RATE          ADJUSTED',
     * '        TOTAL COST'/
     *'      UNIT      UNIT      SIZE    COSTED          ',
     *'UNIT COST        ADJUSTMENT          UNIT COST   ',
     * '    (UNITS COSTED)'/)
  991 FORMAT(I9,I9,I9,I9,F17.3,F17.8,2F17.3)
  990 FORMAT(' INPUT PRAF DATA SPECIFIED BELOW IN ORDER GIVEN',
     *' WITH SPACE BETWEEN NUMBERS:'/'      BASE YEAR QUANTITY'/
     *'      PRIOR YEAR QUANTITY'/)
  989 FORMAT(///////' DO YOU WANT TO RERUN PROGRAM, YES OR NO?')
  987 FORMAT(/' INPUT FISCAL YEAR OF FIRST PROCUREMENT LOT',
     *'S  (4 DIGITS)'/)
  986 FORMAT(/' INPUT DATA SPECIFIED BELOW FOR ADVANCE ',
     *'PROCUREMENT COSTS:'/
     *'      % OF NEXT YEARS GROSS WEAPON SYSTEM REQUIRED FOR ',
     *'ADVANCE PROCUREMENT (DECIMAL)'/'      PRIOR YEAR ADVANCE ',
     *'PROCUREMENT FOR LOT #1  (CURRENT YEAR $ IN MILLIONS)'/)
  900 FORMAT (40X,'*** PROCUREMENT COST SUMMARY ***'/
     *45X,'CURRENT $  IN MILLIONS'/)
 1899 FORMAT(/'                        ',9(7X,A4))
  899 FORMAT( ' FISCAL YEAR            ',9(7X,I4))
  898 FORMAT( /' UNITS COSTED           ',9I11)
  897 FORMAT( ' LOT COST               ',9F11.3)
  896 FORMAT( ' LESS PRIOR AP          ',9F11.3)
  895 FORMAT( ' LOT COST               ',9F11.3)
  894 FORMAT( ' PLUS CURRENT AP        ',9F11.3)
  893 FORMAT( ' LOT COST               ',9F11.3)
  892 FORMAT( ' INITIAL SPARES         ',9F11.3)
  891 FORMAT( ' PROCUREMENT            ',9F11.3)
  909 FORMAT(A3)
  908 FORMAT(A3)
  985 FORMAT(/' INPUT THE 3 PRODUCTION EFFICIENCY RATES (EXAMPLE -- ',
     *  '8 5 3)'/)
      END
```

APPENDIX B

PRAF Symbols

BYQ = Base Year Quantity

PYQ = Prior Year Quantity

IBFY = Beginning Fiscal Year

PAP = % next years GWS required for Advance Procurement

PYAP = Prior Year Advance Procurement for LOT #1

SLOPE = Slope for learning curve factor

RFU = First Unit of Lot of Known Cost

RLU = Last Unit of Lot of Known Cost

RAUC = Average Unit Cost of the Lot

NLOTS = Number of Lots to be Calculated

APA(I) = Lot (I) Escalation Factor

FUN(I) = First Unit in Lot (I)

LUN(I) = Last Unit in Lot (I)

UNC(I) = Number of Units Costed in Lot(I)

SPART(I) = Cost for Initial Spares (Constant)

B = (ln(Slope) ÷ ln (2)) + 1

A = First Unit Cost

UNITS(I) = Number of Units in Lot (I)

AUC(I) = Average Unit Cost for Lot (I)

COVRP = Units in Lot (I) ÷ Units in Lot (I-1)

COVRB = Units in Lot (I) ÷ Base Year Quantity

EXPA = First Production Efficiency Rate

EXPB = Second Production Efficiency Rate

EXPC = Third Production Efficiency Rate

PEXP = EXPB (if COVRP is 1 or greater)

PEXP = EXPC (if COVRP is less than 1)

PRAF = COVRB ** (EXPA) * (COVRP) ** PEXP

TCOST(I) = Total Cost for Lot (I)

ADJUS = AVC(I) * PRAF(I)

GWS(I) = Gross WS for Year (I) = TCOST(I)*APA(I)

IFY(I) = Fiscal Year (I)

APC(I) = GWS (I+1) * PAP = Current Appropriation

APP(I) = GWS(I) * PAP = Prior Appropriation

ANWS(I) = GWS(I) - APP(I) = Net WS

WS(I) = ANWS(I) + APC(I) = Weapon System

PROC(I) = WS(I) + SPARI(I) = Procurement

AD P001237

PROGRAM MANAGEMENT CONTROL SYSTEM (PMCS)

Hal Henry

PMCS KEY EVENTS

- 1 APR 81 - DRAFT CIRCUALR STAFFED
- 18 JUN 81 - DRAFT CIRCULAR APPROVED AND IMPLEMENTED WITHIN DARCOM
- 29 JUL 81 - ARMY VICE CHIEF OF STAFF (VCSA) APPROVAL
- 28 DEC 81 - 38 PMCS WEAPON SYSTEMS DESIGNATED
- 11 JAN 82 - DRAFT CIRCULAR FINALIZED
- 25 FEB 82 - 1ST SYSTEMS SUBMITTED TO HQDA (MLRS)
- 14 JUN 82 - MLRS APPROVED

PMCS SYSTEM COMPONENTS

- PROGRAM DIRECTIVE DOCUMENT (PDD)
- COST BASELINE
- ANNUAL EXECUTION PLAN (AEP)
- MONTHLY STATUS REPORT

PMCS MANAGERIAL VALUE

- INSTILL COST DISCIPLINE
  - STRENGTHEN MANAGEMENT CONTROL
    - INCREASED VISIBILITY OF PROGRAM TRENDS
      - EARLIER IDENTIFICATION OF DIVISION ALTERNATIVES
        - AGREEMENT ON ACQUISITION STRATEGY
          - INDUCE PROGRAM STABILITY (CARLUCCI INITIATIVE #4)

PMCS CIRCULAR 11-1 CHANGES

- IDENTIFYING AND TRACKING OF ILS
- IDENTIFYING AND OF PEP
- SPECIFIC PM "GET WELL" PLAN
- MID RANGE ALTERNATIVE
- EMPHASIS ON ACQUISITION STRATEGY

PMCS STATUS

		NO.
° SYSTEMS COMPLETE PROCESSING	-	1
MLRS		
° SYSTEMS CURRENTLY AT DA	-	7
M1 BFVS AHIP		
HMMWV CH-47		
FOTS (PM ATACS) HELLFIRE		
° SYSTEMS CURRENTLY AT DARCOM	-	12
CHAPARRAL		
OPTADS		
PATRIOT		
HAWK		
PERSHING II		
PLRS/TIDS		
DIVAD		
BLACK HAWK IR SUPP		
MAINSITE		
AAH		
STINGER		
SCOTT (TACSATCOM)		

PMCS STATUS

SYSTEM	CURRENT SCHEDULE
ROLAND	SUSPENDED
TACFIRE	SEP 82
COPPERHEAD	SEP 82
TACTICAL FUSION	SEP 82
TOW II	SEP 82
RPV	SEP 82
VIPER	SEP 82
FISTV	SEP 82
MICNS	SEP 82
ADCCS	OCT 82
MPG-F	OCT 82
SINCGARS	OCT 82
TMDS (DS-ATSS)	NOV 82
BLACK HAWK	NOV 82
QUICK FIX	NOV 82
COBRA	INDEFINITE
AN/TCC-39/TYC-39	INDEFINITE
SOTAS	INDEFINITE

DOD COST ANALYSIS SYMPOSIUM

12-15 SEP 82

VUGRAPH 1 (PMCS HEADER) - ON

THE PROGRAM MANAGEMENT CONTROL SYSTEM (PMCS) WAS DEVELOPED TO PROVIDE MORE EFFECTIVE MANAGEMENT CONTROL AND BETTER COST CONTROL. THE NEED FOR SUCH CONTROLS ARE APPARENT INCREASES IN THE 17 ARMY SAR SYSTEMS. BETWEEN FY79 AND FY81, THE PROGRAM ACQUISITION COSTS (RDT&E, PROCUREMENT AND MILITARY CONTRACTION ARMY) ROSE FROM $50.7B TO $78.5B. MAJOR CONTRACTORS TO THAT INCREASE WERE: ESTIMATING ERRORS, CHANGES IN QUANTITY, SCHEDULES, SUPPORT AND ENGINEERING. IT WAS OBVIOUS THAT IF THESE CHANGES COULD BE CONTROLLED, THEN A MAJOR STEP WOULD BE TAKEN TO ARRESTING COST INCREASES OF THE ABOVE MAGNITUDE.

FORTUNATELY, THE US AIR FORCE SYSTEMS COMMAND, UNDER GENERAL SLAY, HAD ELEMENTS OF A SYSTEM WHICH CONTROLLED SOME OF THESE CHANGES. ONE PORTION OF THE SYSTEM, AFSC R 550-17, DEMANDED THAT FORMAL SYSTEM DEFINITION BE APPROVED BY THE AIR STAFF AND CHANGES TO THAT DEFINITION COULD ONLY BE APPROVED BY THE AIR STAFF.

SECOND, UNDER AFSC R 550-18, PROVISION WAS MADE FOR A FORMAL CONTRACT BETWEN THE PROJECT MANAGER AND THE COMMANDER OVER A CERTAIN DEFINED SCOPE OF WORK AND AN EXECUTABLE LEVEL OF FUNDING FOR THAT SCOPE. IMPLICIT IN THAT CONTRACT WAS THE CONCEPT OF A ZERO GROWTH ALTERNATIVE, IN OTHER WORDS, A LESSENING OF SCOPE TO REMAIN WITHIN BUDGET WHEN A COST GROWTH OCCURRED. ALSO CONTAINED IN THE SYSTEMS COMMAND DIRECTIVE, WAS CONTROLLED DECENTRALIZATION. MAJOR SYSTEMS WOULD BE MANAGED BY HQ SYSTEMS COMMAND WHILE SMALLER SYSTEMS WOULD BE MANAGED BY THE PRODUCT COMMANDERS OF SYSTEMS COMMAND.

USING THESE BASIC ELEMENTS AND WITH ADDITIONAL ARMY RESEARCH, HQ DARCOM TASK WAS TO DEVELOP AND IMPLEMENT A SYSTEM WHICH PROVIDED A FORMAL PROGRAM DEFINITION, A CHANGE CONTROL PROCESS, A TRACKABLE AUDIT TRAIL, A BLUEPRINT FOR PROGRAM EXECUTION, AND A PERIODIC STATUS REPORT. THESE PARTS, THEN, CAME TO FORM THE PMCS SYSTEM. I WILL ADDRESS EACH IN SOME DETAIL LATER.

VUGRAPH 1 - OFF

VUGRAPH 2 (PMCS KEY EVENTS) - ON

THE CHRONOLOGY OF KEY EVENTS FOR PMCS IS AS FOLLOWS:

VUGRAPH 2 - OFF

VUGRAPH 3 (PMCS SYSTEM COMPONENTS) - ON

I WOULD NOW LIKE TO ADDRESS THE SPECIFIC FEATURES OF PMCS. PMCS IS COMPOSED OF FOUR COMPONENTS. THE PROGRAM DIRECTIVE DOCUMENT, THE COST BASELINE, THE ANNUAL EXECUTION PLAN AND THE TRACKING AND EVALUATION MECHANISM WHICH, IN ESSENCE, IS A MONTHLY STATUS REPORT. THESE COMPONENTS, AND THE COMBINATION OF PROACTIVE AND REACTIVE MANAGEMENT ACTIONS WHICH THEY SOLICIT, ARE INTENDED TO PROVIDE A KIND OF MANAGEMENT PROCESS CONDUCIVE TO INFORMED DECISION MAKING. THIS MANAGEMENT SYSTEM POSSESSES SOME VERY BENEFICIAL FEATURES.

(1) THE PDD IS A RELATIVELY CONCISE DOCUMENT WHICH INDICATES THE BROAD DIRCTION AND SCOPE FOR A SPECIFIC WEAPON SYSTEM PROGRAM. THE PROGRAM DEFINITION IN THE PROGRAM DIRECTIVE DOCUMENT REPRESENTS A COORDINATED, AGREED TO ACQUISITION PROGRAM AMONG DARCOM, TRADOC AND THE ARSTAF FOR THAT WEAPON SYSTEM.

(2) THE EXTENT OF THE RESOURCES THAT ARE NEEDED TO CARRY OUT THE DIRECTION IN THE PROGRAM DIRECTIVE DOCUMENT IS CONTAINED IN THE COST BASELINE. THE COST BASELINE QUANTIFIES THE REQUIRED RDT&E PROCUREMENT, MILITARY CONSTRUCTION ARMY (MCA), AND OPERATIONS AND MAINTENANCE (OMA) FUNDS.

(3) THE ANNUAL EXECUTION PLAN (AEP) GIVES A HIGH LEVEL SKETCH OF THE ENTIRE PROGRAM AND A CONCENTRATED LOOK AT THE UPCOMING 12-18 MONTH PERIOD. IT INDICATES SIGNIFICANT MILESTONES AND MANAGEMENT ACTIONS. IT IS A MANAGEMENT DOCUMENT FOR THE HEADQUARTERS, AND A COURSE OF ACTION FOR THE PROJECT MANAGER.

(4) HOW WELL THE PM EXECUTES HIS AEP IS TRACKED IN THE PMCS MONTHLY STATUS REPORT. THE STATUS REPORT CONSISTS OF THREE PAGES AND REQUIRES A PM'S RATING OF HIS PROGRAM IN 11 FUNCTIONAL AREAS (SCHEDULE/QUANTITY, SYSTEM/TECHNICAL, COST, CONTRACT, MANPOWER, ILS, TESTING, INTEGRATION INTERFACE, DESIGN TO COST, PRODUCT ASSURANCE, AND PRODUCTION READINESS). IT ALSO DESCRIBES CORRECTIVE ACTIONS WHERE THERE ARE ADVERSE TRENDS.

(5) THE AEP, UPDATED ANNUALLY, PROVIDES AN AUDITABLE TRACK TO THE PRESIDENT'S BUDGET. THIS ALLOWS CLOSE LINK BETWEEN THE COST ANALYSIS DOCUMENTS AND THE PROGRAMMING/BUDGETING CYCLE.

(6) FINALLY, THERE IS A FORMAL CHANGE CONTROL PROCESS, SHOULD MODIFICATION OF THE PDD BE NEEDED. THE EMPHASIS HERE IS TO REDUCE CHANGE, BUT AT THE SAME TIME, NOT BE INFLEXIBLE.

VUGRAPH 3 - OFF

VUGRAPH 4 (MANAGERIAL VALUE) - ON

PMCS, WITH THE DISCUSSED FEATURES, WILL PROVE TO HAVE SIGNIFICANT MANAGEMENT VALUE.

(1) COST DISCIPLINE WILL BE MADE HIGHLY VISIBLE. BY HAVING A DEFINITIVE AND TRACKABLE PROGRAM, THE COST ASSOCIATED WITH A PROGRAM CHANGE OR RATHER THE EFFECT OF PROPOSED CHANGES ON SYSTEM COST CAN CLEARLY BE PART OF THE DECISION PROCESS.

(2) MANAGEMENT CONTROL WILL BE STRENGTHENED AS A RESULT OF THIS COST DISCIPLINE, MORE INTENSIVE PROGRAM VISIBILITY THROUGH MONTHLY STATUS REPORTING, BUT, MOST IMPORTANTLY, THROUGH THE REQUIREMENT FOR HIGH LEVEL APPROVAL AND DOCUMENTATION OF PROGRAM CHANGES.

(3) THROUGH THE MONTHLY STATUS REPORT, THERE WILL BE EARLIER VISIBILITY OF PROGRAM TRENDS, ESPECIALLY THOSE WHICH ARE ADVERSE. WITH THIS, WILL COME NOT ONLY PROBLEM STATEMENTS, BUT MORE IMPORTANTLY, THE CORRECTIVE MANAGEMENT ACTION.

(4) THE PMCS TRACKING AND EVALUATION PROCESS WILL ALLOW FOR EARLIER IDENTIFICATION OF PROBLEMS AND THEIR ASSOCIATED DECISION ALTERNATIVES, HOPEFULLY REMOVING US FROM THE ALL TOO FAMILIAR SITUATION OF MANAGEMENT BY CRISIS.

(5) IN THE PROGRAM DIRECTIVE DOCUMENT, THE BROAD OUTLINE OF ACQUISITION STRATEGY WILL BE DISCUSSED. THIS WILL INSURE MANAGEMENT COMMITMENT AT ALL LEVELS TO THE APPROVED STRATEGY AND REQUIRE DOCUMENTATION OF DECISIONS AND DIRECTION WHICH STRAYS FROM THAT STRATEGY.

(6) ALL OF THESE FACTORS SHOULD LEAD TO GREATER PROGRAM STABILITY AND THEREFORE, BETTER EXECUTION OF THE PROGRAM. THIS IS THE KEY TO THE SUCCESS OF PMCS, OR TO ANY ACQUISITION MANAGEMENT SYSTEM. IF WE CAN REDUCE PROGRAM TURBULENCE THROUGH REDUCTION OF PROGRAM CHANGES AND INSTITUTE A MORE DISCIPLINED MEANS OF MANAGING THOSE CHANGES THAT ARE

NECESSARY, WE WILL HAVE TAKEN A MAJOR STEP IN IMPROVING THE ARMY ACQUISITION PROCESS. PMCS IS A MECHANISM TO "SIGN UP" TOTAL ARMY MANAGEMENT TO A PROGRAM PLAN AND COMMIT THEM TO MAINTAIN THAT PLAN THROUGH A STABLE ENVIRONMENT.

VUGRAPH 4 - OFF

VUGRAPH 5 (CIRCULAR 11-1 CHANGES) - ON

AS PREVIOUSLY MENTIONED, DRAFT CIRCULAR 11-1 WAS APPROVED ON 11 JANUARY. EXPERIENCE GAINED FROM THE SYSTEMS BROUGHT UNDER PMCS, AS WELL AS RECOMMENDATIONS BY MR. MILLER, CHAIRMAN OF THE COST DISCIPLINE ADVISORY COMMITTEE (CDAC) REQUIRE REVISION OF THE CIRCULAR. AMONG THE MORE SIGNIFICANT REVISIONS ARE:

(1) IDENTIFYING AND TRACKING OF ILS FUNDS AND TASKS IN THE ANNUAL EXECUTION PLAN AND MONTHLY STATUS REPORT. WHILE THE IDENTIFICATION OF DISCRETE ILS ELEMENTS HAS NOT BEEN FINALIZED, THEY WILL INCLUDE, BUT NOT BE LIMITED TO: SPARES AND REPAIR PARTS, SUPPORT AND TEST EQUIPMENT, DOCUMENTATION, TRAINING DEVICES, FACILITIES, DEPOT REPAIR AND ILS/MANAGEMENT ANALYSES.

(2) WHEN APPROPRIATE, IDENTIFYING AND TRACKING OF PRODUCIBILITY ENGINEERING PLANNING (PEP) FUNDS AND TASKS IN THE AEP AND MONTHLY STATUS REPORT.

(3) WHEN SIGNIFICANT DEVIATIONS FROM THE AEP OCCUR, THE PM WILL PROVIDE A SPECIFIC "GET WELL" PLAN IN HIS MONTHLY STATUS REPORT.

(4) WHEN DEVIATIONS INVOLVE SIGNIFICANT COST GROWTH, THE PM, IN ADDITION TO A ZERO COST GROWTH ALTERNATIVE, WILL PROVIDE A MID-RANGE ALTERNATIVE; IN OTHER WORDS, A LESSENING OF SCOPE AND SOME INCREASE IN COST. THIS WILL GIVE HIGHER MANAGEMENT MORE LATITUDE AS WELL AS PROMOTE BENEFICIAL TRADE-OFF ANALYSES BY THE PM.

(5) THERE WILL BE GREATER EMPHASIS ON ACQUISITION STRATEGY, IMPLICIT IN THAT EMPHASIS WILL BE A CLOSE, TRACKABLE LINK BETWEEN THE PMCS DOCUMENTS AND THE ACQUISITION PLAN.

ADDITIONAL MODIFICATIONS TO THE CIRCULAR WILL INCLUDE MORE STRESS ON TIMELY, CANDID REPORTING IN THE MONTHLY STATUS REPORT AND RENEWED EMPHASIS ON CONFIGURATION CONTROL AND ON DISCIPLINED CHANGE CONTROL PROCESS. THE REVISED CIRCULAR WAS SUBSTITUTED THE END OF AUGUST.

VUGRAPH 5 - OFF

VUGRAPH 6 (PMCS STATUS) - ON

DARCOM IMPLEMENTATION OF PMCS IS CONTINUING. THE PROGRAM DIRECTIVE DOCUMENT FOR MLRS HAS BEEN APPROVED. PMCS DOCUMENTATION FOR M1 ABRAMS, HIGH MOBILITY MULTI-PURPOSE WHEEL VEHICLE, FOTS, DFVS, CH-47, AHIP AND HELLFIRE HAS BEEN FORWARDED TO HQDA FOR APPROVAL. DOCUMENTATION ON NINE OTHER SYSTEMS, AS SHOWN, IS CURRENTLY BEING PROCESSED AT THIS HQ AND TRADOC. THESE 26 SYSTEMS REPRESENT APPROXIMATELY ONE-HALF OF THE 38 SYSTEMS INITIALLY SELECTED FOR PMCS.

VUGRAPH 6 - OFF

VUGRAPH 7 (PMCS STATUS) - ON

PMCS DOCUMENTATION ON ADDITIONAL SYSTEMS ARE TARGET TO ARRIVE AT DARCOM MONTHLY THROUGHOUT THIS YEAR.

VUGRAPH 7 - OFF

AD P001238

REDUCE DOD DIRECTIVES

17TH ANNUAL COST ANALYSIS IMPROVEMENT SYMPOSIUM

SEPTEMBER 14, 1982

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51

REDUCE DOD DIRECTIVES

BACKGROUND

INITIATIVE #14 ALLEGATIONS

- ACQUISITION DIRECTIVES GREW FROM 15 (1971) TO 26 (1977) TO 114 (1981)
- MANAGEMENT DATA REQUIREMENTS COST "APPROXIMATELY $8 BILLION PER YEAR"

REDUCE DOD DIRECTIVES

PLAN

- FORM DOD/INDUSTRY REVIEW GROUP
- IDENTIFY ACQUISITION DIRECTIVES (136)
- ANALYZE SET
- DEVELOP RECOMMENDATIONS TO DELETE, CONSOLIDATE, OR IMPROVE
- FORWARD RECOMMENDATIONS TO ACTION OFFICERS
- RESOLVE DIFFERENCES
- SUMMARIZE RESULTS OF "VOLUNTARY" EFFORT
- MANDATE REDUCTION, IF NECESSARY
- PREPARE FINAL REPORT
- PROPOSE PROCEDURES TO REDUCE FUTURE DIRECTIVES GROWTH
- RETURN DIRECTIVES MANAGEMENT TO NORMAL COMMAND CHANNELS

DOD DIRECTIVES REDUCTION

STATUS

136	DIRECTIVES/INSTRUCTIONS REVIEWED BY GROUP
7	HAVE BEEN CANCELED
5	WILL BE CANCELED
7	HAVE BEEN OR WILL BE CONSOLIDATED
46	HAVE BEEN OR WILL BE IMPROVED/REWRITTEN
11	BEING REVIEWED BY ACTION OFFICER
2	NO RESPONSE FROM ACTION OFFICER
26	NO RECOMMENDATION FOR CHANGE BY AD HOC GROUP
29	RETAINED AS IS
3	ELIMINATED FROM LIST (NOT AN ACQUISITION SUBJECT)

DOD DIRECTIVES REDUCTION GROUP

NUMBER ISSUED BY CATEGORY AND ORGANIZATION

CATEGORY	RESPONSIBILITY											TOTAL NO.
	USDRE	MRA&L	ASD(C)	PA	USDP	GC	ISA	ISP	LA	PA&E	JOINT	
SUPPLY, MAINTENANCE & LOGISTICS	1	17										18
INTERNATIONAL COOPERATION	8			1	2	3	2	1				17
MANAGEMENT INFO.	6	(1)*	7(1)*						1	(1)*	1	15
STANDARDIZATION	6(1)*	3(1)*	3								1	13
MANUFACTURING	8	2			2							12
ACQUISITION	9	2										11
ADP	2(2)*	(2)*	4(2)*								2	8
BUDGET GUIDANCE	1		6							1		8
PROCUREMENT	4	4										8
R&D	5	3										8
TECHNICAL INFO.	7											7
MISCELLANEOUS	1			3								4
ENVIRONMENTAL	1	2										3
PERSONNEL	1	1										2
TEST & EVALUATION	1											1
INT'L / BUDGET GUIDANCE			1									1
TOTAL	61	34	21	4	4	3	2	1	1	1	4	136

DOD DIRECTIVES REDUCTION

CONCLUSIONS

- MINIMAL GROWTH IN ISSUANCES IN LAST 10 YEARS
- LIKELIHOOD $8B IS OVERSTATED
  - PROGRAMMATIC NEEDS ARE COST DRIVERS
  - IMPACT ON COST OF OSD MIS IS MINIMAL - 2? OF 30 REQUIRE CONTRACTOR DATA
  - RECURRING CONGRESSIONAL REQUIREMENTS MINIMAL
- "VOLUNTARY" REDUCTION SLIGHT
- NEW DIRECTIVES MANAGEMENT SYSTEM IGNORED AND NOT ENFORCED
- COST BENEFIT OF REDUCTION LIKELY TO BE SLIGHT
- ANY FURTHER REDUCTION MUST BE MANDATED
- NEW ISSUANCES MUST:
  - BE SCREENED FOR DUPLICATIVE MATERIAL
  - ADDRESS ONLY POLICY OR INSTRUCTIONAL MATERIAL
  - BE LIMITED IN LENGTH
  - INCLUDE SUNSET PROVISION, WHERE APPLICABLE

OPTIONS

I

- DEP SEC DEF REQUIRE FROM ASD(C) AND ASD (MRA&L) OR EQUIVALENT
  - RECOMMENDATION FOR DIRECTIVES REDUCTION GOAL
  - PLAN(S) TO REDUCE DIRECTIVES TO GOAL (+25%, 50%, AND 75%?)
- USDRE/USDRE(AM) STEERING GROUP TO:
  - ADDRESS USDRE DIRECTIVES SET
  - IDENTIFY SUBJECT
  - DEVELOP REDUCTION GOAL(S) BY SUBJECT OR ORGANIZATION
  - FORMULATE PLAN
  - EXECUTE
  - REPORT STATUS AND RESULTS TO DEP SEC DEF AS APPROPRIATE

OPTIONS

(CONTINUED)

II

- STRENGTHEN AND ENFORCE TERMS OF DODI 5025.11, "DEPARTMENT OF DEFENSE DIRECTIVES SYSTEM REVIEW PROGRAM," DTD SEPTEMBER 24, 1981 (35 "HITS")
  - UPDATE OR CANCEL ALL DIRECTIVES THAT PRECEDE JANUARY 1, 1970
  - UPDATE OR CANCEL ALL DIRECTIVES MORE THAN 10 YEARS OLD EACH DECEMBER 30TH
  - NEW DIRECTIVES TO CONTAIN "SUNSET" (10 YEAR LIFE) PROVISION UNLESS SPECIFICALLY WAIVED
  - BIANNUALLY CERTIFY NEED FOR EACH ISSUANCE
  - REQUIRE "GIVE-UP" FOR NEW ISSUANCE OR WAIVER

III

- COMBINE OPTIONS I AND II

IV

- ISSUE FINAL REPORT OF RESULTS TO DATA
- CLOSE INITIATIVE

ISSUES

- INITIATIVE #14 EMOTIONAL RATHER THAN FACTUAL ISSUE
  - PROLIFERATION A STATISTICAL MYTH
  - INORDINATELY LENGTHY ISSUING PROCESS
- DIRECTIVES:
  - SAVE DOLLARS AND TIME
  - SUBSTITUTE PROCESS FOR REVIEW OF INDIVIDUAL ACTIONS
  - MINIMIZE SIZE OF STAFF
  - ARE PRODUCT OF AGREEMENT BY AFFECTED GOVERNMENT/INDUSTRY COMMUNITY
- NAVY TENDS TO NON-CONCUR ON NEW DIRECTIVES AND PROPOSE DELETION
- ALMOST HALF OF SET ARE USDRE ISSUANCES

  (USDRE PREPARING MEMO FOR DEPSECDEF TO SEND TO USDRE?)
- MORE DIRECTIVES COMING
- DASD(A) OBJECTS TO "SUNSET" PROVISIONS
  - NOT ENFORCING DODI 5025.11 REVIEW PROCESS

RECOMMENDATIONS

- CONCLUDE EFFORT
- FILE REPORT
- STRENGTHEN DIRECTIVES REVIEW PROCESS
  - ACCEPT OPTIONS II AND IV
  - REJECT OPTION I

AD P001239

RESEARCH PAPER P-5

SOLE SOURCE AND COMPETITIVE PRICE TRENDS IN SPARE PARTS ACQUISITION

by

Charles H. Smith

Charles M. Lowe, Jr.

This paper reflects only the thoughts of the author. It in no way represents the official position of the Army Procurement Research Office, the Army Materiel Development and Readiness Command, or the United States Army.

SOLE SOURCE AND COMPETITIVE PRICE TRENDS IN SPARE PARTS ACQUISITION

I. INTRODUCTION.

While the benefits of competition are widely recognized, most US Department of Defense (DOD) procurement is accomplished in a sole source mode. For example, in FY 79 over 60% of the dollar value of DOD contracts were awarded on a noncompetitive basis [7]. A large portion of the dollars awarded on a sole source basis is related to major systems, both for end item awards and spare parts. For major systems, special studies may be required to investigate the potential risks, costs, and benefits of introducing competition into the system's production phase. Such studies require the estimation of several parameters affecting the acquisition method trade-off. One of the key parameters required is a forecast of the recurring savings to be realized from competition. The data that has been available for assistance is limited [1, 2, 3, 4, 6, 8]. One obvious limitation is the relatively small number of major systems with competitive production histories.

The purpose of this paper is to present empirical data for analysts to consider in making savings forecasts. Two principal questions guided this research:

1. Is the rate of decline in price (constant dollars) more rapid under competitive procurement than under sole source procurement? That is, does competitive procurement reflect a steeper learning (or experience) curve than sole source procurement?

2. What percentage savings is realized on the first competitive buy?

II. DATA.

In order to have a large data base with both competitive and sole source buys, this study examines the price behavior of spare parts for major systems. The data were obtained from the US Army Troop Support and Aviation Materiel Readiness Command. The Command provided a list of over 1300 spare parts which had been competed. These items are used on a variety of Army helicopters and major components.

The complete procurement histories of approximately 200 randomly selected items were screened for possible use of the items in this study. To survive the screening process a candidate item needed to have been procured at least three times in the sole source mode followed by at least three competitive purchases. Another criterion was to avoid items with a gap of several years between consecutive buys to minimize distortion due to dominance of price index effects. A sample of 39 items was finally obtained and analyzed. While 26 items were originally acquired from a single sole source, their learning curve and savings performance paralleled the 13 items from four other sole sources. The unit price of the items ranged from a few dollars to several hundred dollars. The items represented ten Federal Supply Classes used in Army aviation.

Several adjustments were necessary to transform the data into a form suitable for analysis. Prices were adjusted to a constant dollar basis using the producer price index for metal and metal products [10]. This index, being rather specific to the sample products, should better enable true competitive effects to be revealed. The midpoint between the date the contract was effective and the date the contract was physically completed was used for price index adjustment. In order to use the typical concepts of learning curve theory, accurate cumulative production quantities were required for each item for each contract period. To obtain cumulative quantities, the production of the item as a part of its applicable end

article system contracts was separately determinec. These quantities were added to the replacement contract quantities which were already available on the procurement history files. Price data for an individual item was available on the procurement history file for all buys.

III. ANALYSIS.

The data analysis is prefaced with the following observations. First, nonparametric statistical tests are used since past studies have revealed that the data in this area tends to be highly variable and does not reflect a clear underlying distribution. Second, the basic premise on which this analysis rests is that prices (y) are reflected by a learning (or experience) curve: $y = ax^{-b}$, where x represents the cumulative quantity and y the price of the x^{th} item. The learning curve slope is given by $2^{-b} \times 100\%$. For example, a slope of 80% means that each doubling of quantity reduces the unit price by 20%. Finally, key data are displayed in the Appendix.

The first issue tested deals with differences in learning curve slopes between competitive and sole source procurement. One theory explaining competitive price behavior suggests that competition induces a downward shift from the sole source learning curve and possibly a change in its slope. This viewpoint on projecting savings due to competition is illustrated in Figure 1. A steeper learning curve due to competition (line C) leads to the projection of much higher future savings than the alternative shown by line B. Line B illustrates the case where the learning rate is unchanged by the introduction of competition. Empirical evidence bearing on this issue is scanty [4, 9]. In past analyses the slopes have been assumed to be the same or different with little basis for either.

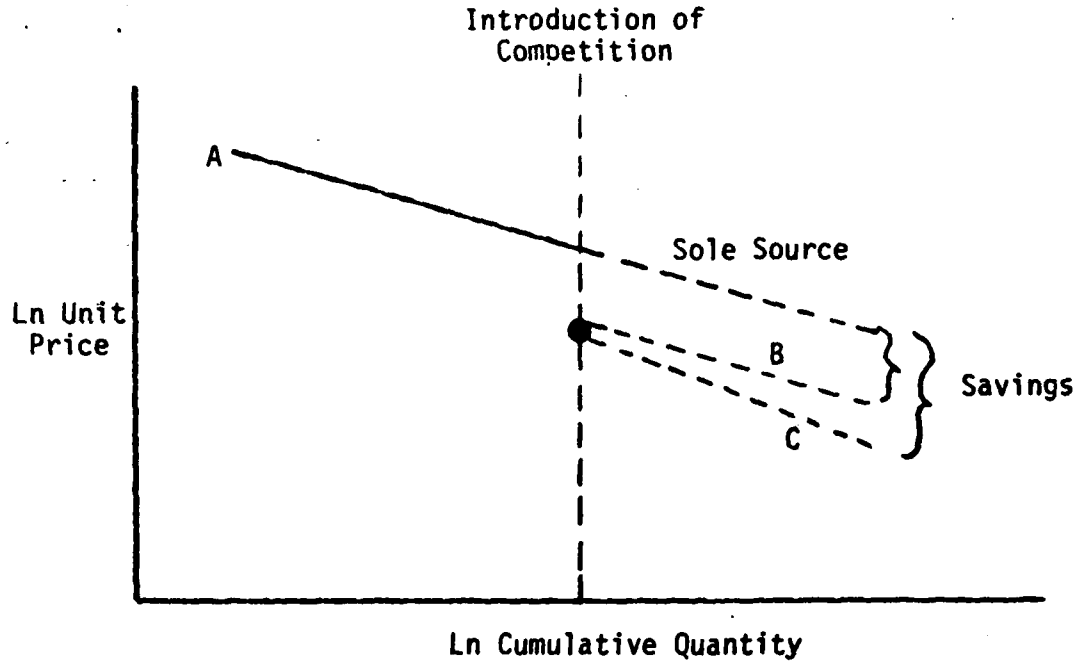


Figure 1 -- Models for Price Behavior
Under the Introduction of Competition

Explicitly stated, the null hypothesis is as follows:

> H_0: The learning curve (i.e., price improvement) slope for a product procured sole source is the same as the slope for that item procured competitively.

To test this hypothesis, least-squares regression lines were fitted separately to both the sole source and competitive portions of each of the 39 sample items. The data points were weighted according to the order quantity they represented. The fitted lines were based on the logarithmic transformation of the price improvement curve: $\ln y = \ln a + b \ln x$.

The sign test was applied to the differences in slopes between sole source and competitive portions of the buy for each item. There was an

overall tendency for competitive slopes to be steeper, but the result was not statistically significant. Twenty-three cases had steeper slopes under competition, and sixteen cases had steeper slopes during the sole source portion of the buy. Almost identical results were obtained when equal weighting was given to each data point with only one case switching sign. However, the order quantity weighted regressions are felt to be more logically defensible. Statistical highlights of the learning curve data are displayed in Table 1.

Table 1

Statistical Summary and Sign Test Results:

Sole Source Slope Minus Competitive Slope

Sample Median	28.2
95% Confidence Band for Estimate of Population Median	[-12.7, 45.7]

Sign	No. of Cases
+	23
-	16

$\underline{\alpha}$ = .13 for 1-sided test of H_0 vs H_1: SS slope > Competitive slope.

The slope data were treated as paired data since a slope of each type was computed for each of the 39 items. Moreover, in the typical analysis using results from a study such as this, one is interested in the savings achieved in shifting a particular product from sole source to competitive

procurement. Application of the Kendall test for independence [5, pp. 185-194], however, showed a lack of correlation between the competitive and sole source slopes for an item. The hypothesis of independence between the two slopes is accepted ($\underline{\alpha} = .3$, where $\underline{\alpha}$ is the lowest level of significance calling for rejection of the null hypothesis). Thus, knowing the sole source slope seems to be of no benefit in predicting the competitive price improvement slope.

Examination of these slopes as independent data suggested that more slope variability occurred under competitive conditions. Indeed, further statistical tests indicate that the two samples of learning curve slopes can be considered drawn from different distributions. That is, the dispersion of the competitive slopes is greater than that of the sole source slopes, and it is unlikely that this dispersion can be attributed to mere randomness. The Moses ranklike test [5, p. 93] was used to test for a difference in dispersion for the two populations. The finding was significant with $\underline{\alpha} < .05$.

Having examined slope effects, the principal remaining question concerns the percentage savings expected on the first competitive buy. The regression lines fitted previously to the sole source cases were projected to the cumulative quantity appropriate for the first competitive buy. This estimated sole source price was compared with the actual competitive price. The sign test was applied, and it was concluded that a savings resulted from the introduction of competition. The statistical test is summarized in Table 2. Note that for ten of the 39 cases the projected sole source cost is less than the competitive cost.

Table 2

Estimate of Savings - First Competitive Buy

Sample Median	24.3%
95% Confidence Band for Estimate of Population Median	[3.4, 37.3]

Sign	No. of Cases
+(Savings)	29
-(Loss)	10

$\underline{\alpha}$ = .0012 for 1-sided test of H_0: Median Savings = 0 vs H_1: Median Savings > 0.

An attempt was made to determine whether certain factors applying to sub-samples would alter the savings forecast. For example, most of the cases contained buys under small purchase procedures which is a limited type of competition. The nine cases in which no competitive buys were done by small purchase methods were examined separately. Three of these cases had negative savings projections, and the sub-sample's overall behavior did not differ significantly from the remainder of the sample.

Another test was made to determine whether order quantities were affecting the savings results. The quantity of the first competitive order for each item was expressed as a percentage of the three largest sole source buys for that item. The Kendall test for independence was used [5, p. 185]. The null hypothesis of independence between order size and savings percentage was accepted. Thus, the savings percentage could not be predicted from knowledge of the relative order quantity.

A statistical test for independence [5, p. 185] was performed to assess whether a relationship existed between the percentage savings on first competition and the subsequent competitive improvement curve slope. The null hypothesis of independence was rejected with $\alpha < .05$ for a 2-sided test. Thus, the higher percentage savings tended to be matched with the flatter price improvement curves.

The final question investigated is whether the median savings determined from this sample agrees with the findings of other studies. The Wilcoxon rank sum test [5, p. 68] was performed to assess whether the savings found in this sample and the savings found in Lovett and Norton [6] could have come from populations with the same medians. The result is that this data and the Lovett and Norton data appear compatible in their savings estimates despite being focused on different types of products ($\alpha = .4$). The median recurring savings from the Lovett and Norton data was 11.9% [6, p. 68] versus 24.3% reported in this study. Although the two sample medians are substantially different, the great dispersion of the data in both samples results in an inability to distinguish between their underlying populations.

IV. SUMMARY AND CONCLUSIONS.

The basic intent of this study is to provide additional empirical evidence to analysts evaluating whether a system ought to be competed to obtain overall cost savings. Although the items studied were not major systems themselves, they were components of major systems, and unlike major systems they were numerous enough to readily test statistically. The extent to which these items have competitive savings behavior similar to that of major systems is not known. Comparison with Lovett and Norton data [6],

however, suggested similar characteristics may be present.

The findings of this study are fairly consistent with other related research. An analyst would be prudent to treat sole source and competitive learning curve slopes as equal or with slight improvement for competition, and to remember the greater variability of competitive slopes. A reasonable percentage savings estimate is likely to be between 15% and 25% with the distribution modified by specific considerations of the system under study.

SELECTED REFERENCES

1. Brannon, R. C. et al., Forecasting Savings from Repetitive Competition with Multiple Awards, Army Procurement Research Office, APRO 807, Fort Lee, VA, 1979.

2. Burt, D. M. and J. E. Boyett, Jr., "Reduction in Selling Price After the Introduction of Competition," Journal of Marketing Research, 16, 275-279 (1979).

3. Daly, G. G. et al., The Effect of Price Competition on Weapon System Acquisition Costs, Institute for Defense Analyses, P-1435, Arlington, VA, 1979.

4. Drinnon, J. W., and J. S. Gansler, "Predicting the Costs and Benefits of Competitive Production Sources," Proceedings of the Ninth Annual DOD/FAI Acquisition Research Symposium, pp. 15-31 to 15-40 (1980).

5. Hollander, M. and D. A. Wolfe, Nonparametric Statistical Methods, John Wiley and Sons, Inc., New York, 1973.

6. Lovett, E. T. and M. G. Norton, Determining and Forecasting Savings from Competing Previously Sole Source/Noncompetitive Contracts, Army Procurement Research Office, APRO 709-3, Fort Lee, VA, 1978.

7. Military Prime Contract Awards by Service Category and Federal Supply Classification, FY 79, Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports, Washington, D.C.

8. Olson, A. E. et al., A Cost-Benefit Analysis of Competitive Versus Sole-Source Procurement of Aircraft Replenishment Spare Parts, Master's Thesis, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 1974.

9. Scherer, F. M., The Weapons Acquisition Process: Economic Incentives, pp. 119-126, Harvard University, Boston, MA, 1964.

10. Statistical Abstract of the United States, Annual Publication of the Bureau of the Census, Department of Commerce.

APPENDIX

I. TRANSFORMED DATA SUMMARY

Item	Sole Source Learning Curve Slope (%)	Competitive Learning Curve Slope (%)	Sole Source Slope - Competitive Slope	Savings on First Competitive Buy (%)	Number of Buys: Sole Source	Number of Buys: Competitive
1	71.6	101.0	-29.4	6.5	7	4
2	93.4	8.2	85.2	1.5	7	4
3	67.7	44.7	23.0	-9.7	6	9
4	83.2	12.8	70.4	9.8	3	5
5	108.3	81.3	27.0	51.3	3	6
6	85.1	51.8	33.3	31.9	3	6
7	127.3	229.1	-101.8	24.3	4	6
8	84.7	48.2	36.5	-4.9	3	9
9	90.7	101.0	-10.3	24.2	11	9
10	89.4	9.0	80.4	43.8	14	3
11	73.6	45.4	28.2	9.1	10	8
12	97.3	152.1	-54.8	71.2	4	10
13	501.5	126.4	375.1	84.8	5	5
14	135.9	39.6	96.3	59.5	7	5
15	109.1	95.0	14.1	53.6	3	7
16	85.9	1719.1	-1633.2	58.2	7	9
17	60.5	73.2	-12.7	33.7	3	3
18	23.5	88.6	-65.1	-2.2	4	5
19	56.7	84.7	-28.0	-28.1	3	6
20	97.7	270.7	-173.0	62.5	3	5
21	115.6	45.5	70.1	-5.8	5	7
22	35.1	73.0	-37.9	-28.8	3	3
23	83.2	0.0	83.2	27.6	5	3
24	113.1	64.8	48.3	57.3	11	7
25	130.2	84.5	45.7	8.4	3	6
26	144.4	30.3	114.1	3.4	4	7
27	86.4	114.8	-28.4	50.9	11	6
28	89.0	2.0	87.0	-11.7	8	3
29	91.8	92.3	-0.5	9.9	3	3
30	89.7	+29342.3	-29252.6	37.3	14	6

I. TRANSFORMED DATA SUMMARY (CONT'D)

Item	Sole Source Learning Curve Slope (%)	Competitive Learning Curve Slope (%)	Sole Source Slope - Competitive Slope	Savings on First Competitive Buy (%)	Number of Buys: Sole Source	Number of Buys: Competitive
31	109.9	189.7	-79.8	-15.9	4	4
32	87.3	113.9	-26.6	26.7	4	5
33	104.4	42.7	61.7	29.1	7	6
34	98.5	60.0	38.5	2.2	4	3
35	87.9	43.2	44.7	77.4	7	9
36	94.2	53.1	41.1	33.1	3	11
37	92.0	0.1	91.9	-28.6	5	3
38	90.4	101.3	-10.9	57.7	9	10
39	35.9	0.0	35.9	-542.4	4	3

II. SUMMARY STATISTICS

A. Competitive Learning Curve Slopes

Median	73.0
95% Confidence Band on Estimate of Population Median	[45.4, 95.0]

B. Sole Source Learning Curve Slopes

Median	90.4
95% Confidence Band on Estimate of Population Median	[85.9, 97.7]

C. Sole Source Slope Minus Competitive Slope

Median	28.2
95% Confidence Band on Estimate of Population Median	[-12.7, 45.7]

D. Savings on First Competitive Buy (%):

Median	24.3
95% Confidence Band on Estimate of Population Median	[3.4, 37.3]

STUDY TEAM COMPOSITION

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This paper has been submitted to the National Contract Management Journal for possible publication.

Summary of the Data Problem
Edward F. Laughlin

Cost Analysis and Cost Estimating in DOD has been making quite a few headlines lately. Although normally one would appreciate the publicity, unfortunately most of this has been adverse. The GAO and the various audit agencies have been persistent reporters of our cost estimating activities. Largely -- all of these reports have addressed themselves to what we do badly, -- or what we may not be doing at all. Unit prices on sophisticated hardware are quoted at double and triple other media numbers, often on the very same day. What is their data base? I would like to take a few minutes to speak to our common data problem in cost analysis.

The specific objectives of cost analysis in support of the materiel acquisition process include identifying and summarizing the expected total resource requirements of materiel systems, recommending cost goals for those systems and validating those estimates through independent costing methods. The collection of data and the structuring and maintenance of a credible data base to adequately respond to these objectives is a continuous struggle by all DOD analysts. We have all experienced the characteristics of new military programs, i.e., increasing complexity and diverse technical nature, multiple labor skill demands, use of more sophisticated materials, requirements for management control systems, and interactions with other systems/organizations/environment, etc. Following upon these characteristics are the work assignements with which we are so familiar, i.e., Baseline Cost Estimates, Independent Estimates, SSEB Estimates, COEAs, updates, "what if(s)," etc. All of these activities demand much cost data and bring about those common data problems of large volume of data, redundancy of data, discovering that data sources don't always agree and then the limitations of the available contracts/contractor data.

No amount of sophisticated statistical analysis can compensate for gross inadequacy in the data base. Since the data problem is fundamental, our analysts devote most of their time to collecting data, to making adjustments in the raw data to help insure consistency and comparability, and to providing for proper storage of information so that it may be retrieved rapidly when it is needed.

DOD has been developing information systems and collecting a huge volume of data in numerous areas for many years; contractors in the aerospace industries have been doing the same thing.

There is the often stated declaration: "If there is a data problem, let's solve it once and for all by establishing the information collection system to meet all our needs." Answers have fallen into the following categories:

a. A cost analyst who is working in support of the long-range planning process cannot specify his information needs once and for all. Data and information requirements are not constant over time, or even for a given small interval of time. Hence, an all purpose information system is not possible.

b. Large information systems can be very expensive. The question to be asked would be: Would the large incremental cost of a new complete information system be justified in terms of the benefits to be derived? (In the long-range planning context, high precision in an absolute sense is usually not a prime requirement.)

Tab 1

c. DOD has to deal with rapidly changing technology. This means that in many instances, only a relatively small number of objectives will be available for a certain time frame or type of technology.

And then, there is always the question: "How can there be a data problem?" More specifically:

a. Information in the wrong format. Present information systems generate a tremendous amount of data. In many instances, however, these data are not in the appropriate format to be very useful in a cost analysis activity directed to serve a long-range planning process. These information systems were established primarily to serve the needs of: (1) managers of functional areas of operational activity, (2) managers responsible for fiscal accounting requirements, (3) managers concerned with critical resource items, and (4) managers of the budget. Little or no provision has been made for making meaningful translations reflecting impacts on cost analysis studies.

b. Integration problem. The analyst (in the development of CERs) must not only collect historical cost data in the right format, but must also obtain information of quantities, physical and performance characteristics, usage/ "flying hour" rates, and other types of cost data points.

c. Differences in definitions of categories. Problem occurs when the definition of content of categories in the input structures set up for the cost analysis fails to correspond to the definition of analogous categories in the existing data and information collections systems. It is not possible to set up an input structure that will simultaneously meet the requirements of cost analysis in support of long-range planning and be in complete harmony with existing data systems at any point in time.

d. The influences of temporary factors. Information collection systems themselves have a habit of changing over time. For example, the appropriate definition of the content of various categories being used to accumulate the historical data may change as the system evolves. DOD deals with a rapidly changing environment, both in hardware and organizational and operational concepts. Almost by definition, this means that even with a near perfect information collection system, only a relatively small sample of data can be generated for a given time frame or class of technology.

e. Comparability problems. The need for comparability among various case histories is generally a requirement in major cost analysis studies. The effort to collect data on a certain class of equipment for more than one military service typically gives rise to what might be called "The Interservices Comparability Problem." Significant differences, differential and otherwise, in the systems used to collect information in the DOD still exists. Moreover, there still remains the differences in the accounting systems among the contractors.

To summarize, the data base is deficient in one way or another:

- Information is usually in the wrong format for analytical purposes.
- Various irregularities, inconsistencies, and noncomparabilities are always present.

- Gaps in information must always exist at various critical points.

- Only a small number of relevant cases from the historical record may be available.

We never seem to have the leisure for development and the necessary time to gather all of the data elements we feel is necessary. We seem to work with a premeditated chaos. It is improbable that a system of a standard data base can be developed to satisfy all of the many and varied crisis informational requirements. Efforts to reach this end would inevitably produce a torrent of information - much of it in unusable form, outdated, and inaccurate. Of equal concern, demands for unnecessarily detailed information superimposed on already overburdened reporting systems would be detrimental to any crisis management process. We must, on the other hand, provide for the collection, evaluation, and storage of essential planning data as immediately available; accurate operational information is vital to effective crisis management. Ideally, of course, pertinent data, structured generally, would be prepared in appropriate detail prior to a crisis. A complementary objective should be the development of an effective process for the rapid analysis of the fragmentary and often conflicting data received from many sources during the course of a crisis. Hopefully, these capabilities will evolve from current and projected development efforts.

AD P001240

USAAVRADCOM

PRESENTATION TO THE

SEVENTEENTH ANNUAL DOD COST ANALYSIS SYMPOSIUM

WORKSHOP: ESTIMATING THE COST OF A PROGRAM - CASE HISTORY

"The Advanced Scout Helicopter (ASH) Estimating"

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"THE ADVANCED SCOUT HELICOPTER (ASH) ESTIMATING"

VIEWGRAPHS

OUTLINE

COMMAND MAP

MODEL 406 DESIGN FEATURES

AHIP HISTORY

COST DEFINITIONS

COST ESTIMATES

REASONS FOR ESTIMATE DEFFERENCES

LESSON LEARNED

I will follow the outline shown in my discussion today. I think you should know a little about the U.S. Army Aviation Research and Development Command and the Army's Helicopter Improvement Program (AHIP) before I discuss the cost problems we had and the experience we had with our ASH estimating.

PRESENTATION OUTLINE

- OVERVIEW OF COMMAND
- AHIP PROGRAM
- COST DEFINITIONS
- COST ESTIMATES
- REASONS FOR DIFFERENCES
- LESSON LEARNED

OUTLINE

- OVERVIEW OF COMMAND
- AHIP PROGRAM
- COST DEFINITION
- COST ESTIMATES
- REASONS FOR DIFFERENCES
- LESSON LEARNED

OVERVIEW OF COMMAND


US ARMY AVIATION RESEARCH
AND DEVELOPMENT COMMAND
PROPULSION LAB
AVIONICS R&D ACTV
BOEING-VERTOL
PLANT REP
HQ RSCH & TECH LABS/
AEROMECHANICS LAB
HQ AVRADCOM
STRUCTURES LAB
APPLIED TECH LAB
AVN ENGR FLIGHT ACTV
HUGHES PLANT
REP
BELL PLANT REP

INTRODUCTION

USAAVRADCOM HAS AN AUTHORIZED MANPOWER LEVEL OF OVER 2000 AND AN ANNUAL OPERATING BUDGET OF APPROXIMATELY $800 MILLION WITH THE ASSIGNED MISSION OF CONDUCTING AND MANAGING RESEARCH, DEVELOPMENT AND ACQUISITION OF U.S. ARMY AVIATION AIRCRAFT SYSTEMS. FUNCTIONALLY, THE COMMAND PLANS, DIRECTS, ACCOMPLISHES AND SUPERVISES THE DESIGN, DEVELOPMENT AND MAJOR MODIFICATION OF AIRCRAFT SYSTEMS, AND SUBSYSTEMS AND PROVIDES FULL TECHNICAL AND ADMINISTRATIVE SUPPORT TO PROJECT MANAGEMENT OFFICES. ITS ASSIGNED AERONAUTICAL MATERIEL INCLUDES BOTH FIXED AND ROTARY WING AIRCRAFT SYSTEMS, DRONES, GROUND SUPPORT DEVICES AND ANCILLARY EQUIPMENT AND AIRBORNE COMMUNICATION SYSTEMS. WE HAVE LABORATORIES CO-LOCATED WITH NASA DESIGN/TEST FACILITIES AT THREE OTHER LOCATIONS AND OUR PROGRAMS ARE INTERNATIONAL IN SCOPE, INVOLVE MAJOR AND HIGHLY DYNAMIC ADVANCES IN TECHNOLOGIES, HAVE SIGNIFICANT IMPACT ON INDUSTRY, AND ARE ESSENTIAL TO THE TOTAL DEFENSE POSTURE.

MISSION AND FUNCTIONS:

a. AVRADCOM IS THE DARCOM LEAD COMMAND FOR CURRENT AND FUTURE ARMY AVIATION RELATED RESEARCH DEVELOPMENTS, AND INITIAL PROCUREMENT. WHILE AVRADCOM HEADQUARTERS IS IN ST. LOUIS, MISSOURI, AVRADCOM ACTIVITIES ARE LOCATED THROUGHOUT THE UNITED STATES.

b. THE AVRADCOM ORGANIZATION INCLUDES THE PROPULSION, STRUCTURES, AEROMECHANICS, AVIONICS, AND APPLIED TECHNICAL LABORATORIES: A FLIGHT TEST ACTIVITY AND; ARMY PLANT REPRESENTATIVE OFFICES AT BOEING VERTOL, BELL HELICOPTER TEXTRON, AND HUGHES HELICOPTERS, INC. PROJECT MANAGERS FOR THE CH-47 MODERNIZATION, THE ARMY HELICOPTER IMPROVEMENT PROGRAM, THE REMOTELY PILOTED VEHICLE, AND THE AIRCRAFT SURVIVABILITY EQUIPMENT ARE LOCATED WITH THE AVRADCOM HEADQUARTERS IN ST. LOUIS. THE PM FOR THE ADVANCED ATTACK HELICOPTER IS UNDER THE DIRECT CONTROL OF HQ DARCOM; IT IS CO-LOCATED WITH HQ AVRADCOM FOR ADMINISTRATIVE SUPPORT. THE TRI SERVICE JVX PM WILL ALSO BE LOCATED AT AVRADCOM.

AHIP PROGRAM

MODEL 406 DESIGN FEATURES

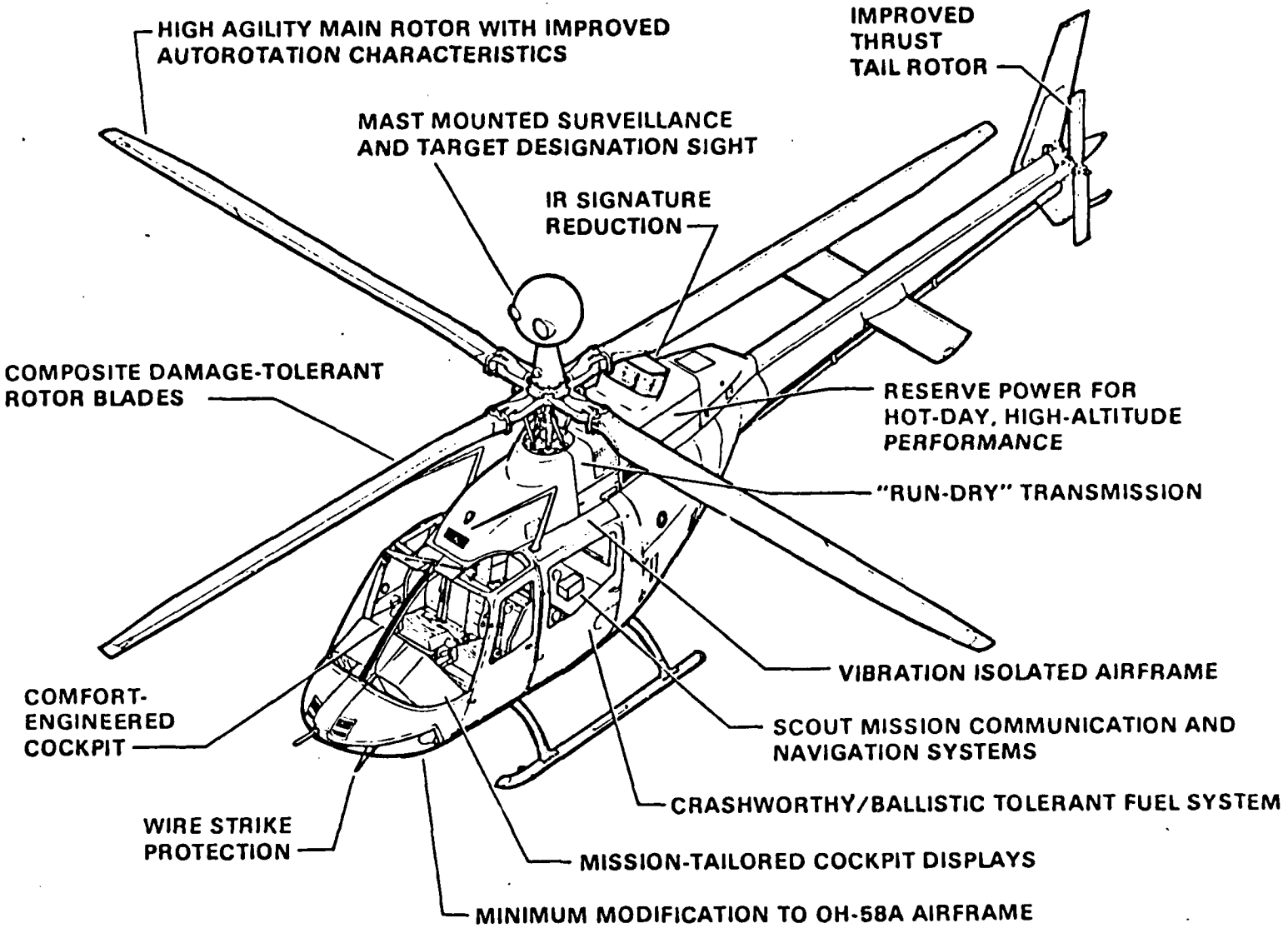


FIGURE 1

AHIP HISTORY

1972 - New Initiatives Aerial Scout Development

1974 - 1975 - Task Force Studies

1975 Feb - ASARC

1975 Sep - DSARC

1976 Mar - DSARC

1977 - - Congress Denied Funds

1978 Jan - Up-Dated ROC

1978 Oct - PM Appointed

1979 June - RSI Study Completed

1980 July - ASARC

1981 Jan - RFP

1981 Sep - Contract Award

AHIP

THE ARMY'S IMPROVED SCOUT HELICOPTER

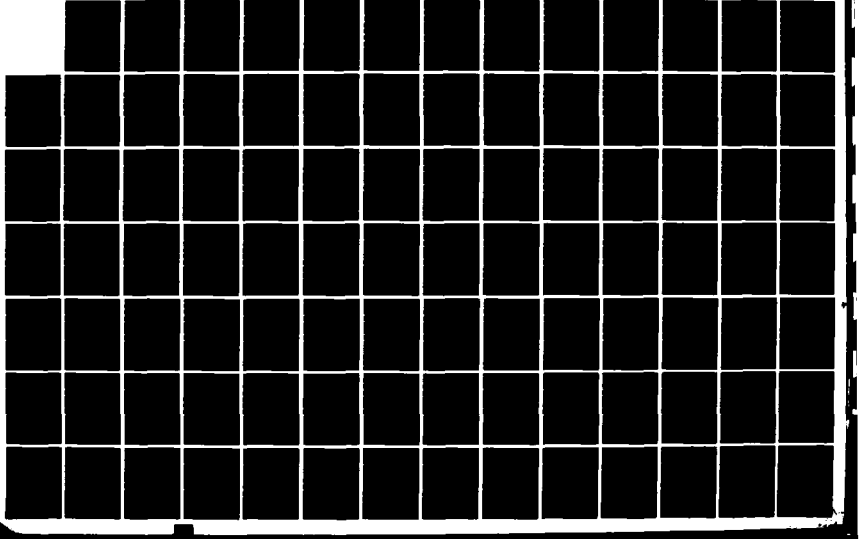
The Army Helicopter Improvement Program (AHIP)is a success story in the checkered history of the Army's efforts to initiate a fully integrated scout helicopter development program. The Army's extensive endeavors to acquire an Advanced Scout Helicopter (ASH) were formally initiated in 1972 when contracts were awarded to Bell and Hughes for a New Initiatives Aerial Scout (NIAS) development effort. The program was structured as a feasibility demonstration to examine improvements to current Light Observation Helicopters (LOH's) such as stabilized optics, a night vision system, a computerized navigation system, laser equipment, and improved survivability features. This program was terminated in November 1972 when Congress disallowed the FY 1973 budget request. The Army was instructed to re-evaluate and redirect the program. NIAS development efforts included the Observer's Target Acquisition System (OTAS) and the Pilot's Night Vision System (PNVS), which were later incorporated into the AH-1G OPTIC aircraft and used to validate Advanced Attack Helicopter (AAH) and ASH night vision requirements.

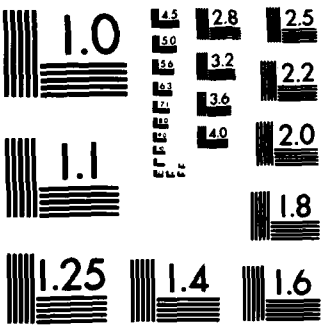
Although effectively causing termination of the NIAS program, Congress did not dispute the Army requirements for a helicopter which would perform night as well as day aerial scout missions in the mid-intensity combat environment. The need for an aerial scout continued, and pending approval to pursue development of a fully capable scout helicopter, a performance improvement modification of the OH-58 (designated the OH-58C) was undertaken.

During 1974 and early 1975, a task force appointed within the Army studied the aerial scout mission and arrived at the basic requirements and

AD-A130 418 DEPARTMENT OF DEFENSE ANNUAL COST ANALYSIS SYMPOSIUM (17TH) HELD AT ARLIGTON VIRGINIA ON 12-15 SEPTEMBER 1982(U) OFFICE OF THE CHIEF OF NAVAL OPERATIONS WASHINGTON DC SEP 82 5/6

UNCLASSIFIED F/G 15/5 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

program structure for the ASH. A firm and valid requirement for a scout helicopter was reconfirmed, and the program advanced through ASARC/DSARC I in February 1975 and September 1975, respectively. A draft Request for Proposal (RFP) was prepared and released to industry for comment, and a Project Manager (PM) was designated.

Both the Army and DOD concluded that some commonality between the ASH and potential future helicopters in the same weight class, such as light attack or light utility, was probably achievable. In March 1976 the DSARC again reviewed the program, reaffirmed support for a helicopter in the ASH weight class, and approved development of a Target Acquisition and Designation System (TADS) and PNVS to be common to the ASH and the AAH.

Subsequent Congressional action denied the ASH FY 1977 fund request as premature, increased the AAH funding to provide for TADS/PNVS development, and called for disestablishment of the ASH PM office. Congress, however, indicated that the ASH program would be considered later if proposed by the Army.

In July 1977, a TRADOC Systems Manager (TSM) office was established at Ft. Rucker, Alabama, to represent the user in all scout helicopter matters. HQDA tasked TRADOC to update the ASH Required Operational Capability (ROC), which had been approved in November 1974. This updated ROC, submitted in January 1978, emphasized survivability and the incorporation of technology advances not available in 1974. The DA ASH acquisition strategy was redefined, necessitating update of the Concept Formulation Package (CFP) to provide quantifiable answers to such questions as scout-attack mix, ASH configuration versus current airframes, and armament and configuration requirements of a new development approach.

The Army's request for FY 1979 funds to support these analyses and tradeoff studies was approved by Congress, and in August 1978, a joint user/developer ASH Special Study Group (SSG) was formed to conduct a comprehensive ASH Cost and Operational Effectiveness Analysis (COEA); to update the ROC, Mission Element Needs Statements (MENS), CFP, and Decision Coordinating Paper (DCP); and to recommend a preferred system or systems to perform the ASH mission. In September 1978, the Study Advisory Group (SAG) for the ASH SSG met for the first time and approved the outline study plans. In October 1978, Colonel Ivar W. Rundgren, Jr. was appointed as the PM designee for the ASH program.

During 1979, a study by helicopter European manufacturers was conducted to determine potential ASH Rationalization, Standardization, and Interoperability (RSI) suitability within the NATO forces. ASH design study contracts were awarded to Societe Nationale Industrielle Aerospatiale, Messerschmitt-Boelkow-Blohm GMBH and Construzioni Aernautiche Giovanni Agusta in April 1979. This effort was completed in June 1979 and resulted in two potentially viable candidates--the Agusta A-129 and the Aerospatiale AS-350--which were then included in overall ASH COEA and SSG deliberations.

The ASH Special ASARC (November 1979) recognized that a pressing need existed for full ASH capability. Two factors, however, deterred approval: (a) a solution was required earlier than could be accomplished by a new development, and (b) a new development effort was not presently affordable. The Special ASARC determined that Mast Mounted Sight (MMS) technology was sufficiently mature to apply to an existing airframe, and redirected efforts toward a near term program to furnish needed capability compatible with the near term attack helicopter fleet, and also serve as a logical step toward longer range objectives for the most survivable combat force.

Following the ASH Special ASARC, the OSD Program Review (December 1979) reinforced the near term program redirection and led to discontinuance of ASH RDTE funding which was replaced by the AHIP budget line effective FY 1981. OSD also stipulated that the OH-58 and UH-1 be addressed as AHIP airframe alternatives.

Intensive efforts ensued to reformulate program documentation, acquisition strategy, and to complete technical/operational suitability analyses concerning AHIP alternatives. Mission profile "live" tests conducted with the OH-58 and UH-1 concluded that the UH-1 was not suitable because its size resulted in higher detectability and increased main and tail rotor strikes when operating in nap-of-the-earth (NOE) environment. These findings caused reconsideration of the OH-6 as an alternative along with the OH-58.

A pragmatic recognition of potential worldwide (versus European-only) commitment of the scout with rapid deployment forces caused reinstatement of more stringent operational performance requirements in the AHIP proposed ROC. The Army presentation to the July 1980 ASARC Review, therefore, recommended a competitive modification program for performance-improved versions of the OH-58 and OH-6A aircraft. The ASARC Principals approved this recommendation.

In July 1980, approval was obtained for a total systems acquisition strategy (entailing single contractor development and integration of the mission equipment). This approach was selected based on reduction of technical and schedule risks by placement of overall mission equipment/aircraft interface and system performance/integrity responsibilities with the aircraft prime manufacturer.

Specific AHIP performance and mission equipment requirements were defined through joint efforts of the US Army user and developer communities.

Briefly, these requirements are: provide day and night target acquisition and designation; improve NOE communication, navigation and target location capabilities; provide performance and maneuverability margins in NOE and hot-day environments; and achieve an acceptable level of crew workload and survivability. The requirements were articulated in a solicitation to industry in January 1981, and proposals were received from Bell and Hughes in April 1981. An evaluation board, made up of the best available expertise from Army technical and user elements and industry consultants, very carefully compared proposed system capabilities with the requirements. In preparation for the board, computer simulation models had been developed and correlated with available test data. These models were used to develop independent Government estimates of capabilities to substantiate proposed system performance. On 21 September 1981, after appropriate decision reviews at senior Army and OSD levels, a contract was awarded to Bell Helicopter Textron, Ft. Worth, Texas, for the development of the Bell Model 406 scout helicopter (Figure 1). The program includes modification of the US Army OH-58A to the AHIP configuration, qualification, and delivery of five AHIP prototypes to the Army for development and operational tests starting in July 1984.

To fully appreciate what the AHIP program brings to the battlefield, we need to recognize that current scout helicopters are inadequate in all areas critical to the scout mission. The OH-58A is significantly underpowered, has only visual (eyeballs/binoculars) target acquisition, limited NOE communications range, and still requires the pilot and/or observer to use a hand-held map for navigation. Additionally, the OH-58 aircraft does not have the capability to designate a target for terminally guided munitions (HELLFIRE, COPPERHEAD, and US Air Force precision guided munitions). Most other

scout pilot will acknowledge the fact that the scout mission often overwhelms the capabilities of the current aircraft and existing mission equipment. Each limitation of the current scout has been addressed and will be eliminated or substantially improved as a result of the AHIP modification program.

The current lack of aircraft performance in the NOE environment is resolved in the AHIP through the following modifications: (1) upgraded engine (Allison 250-C30) which produces up to 650 Shaft Horse Power (SHP) (30 minute limitation) or 600 SHP for continuous operation, (2) improved drive system which includes a transmission rated at 609 SHP (transient) and 435 SHP (continuous), strengthened drive train components, improved tail rotor thrust, four bladed main rotor, and three axis stability augmentation system with heading hold.

The power train modifications will provide the following aircraft performance at primary mission gross weight:

Altitude/temperature	Vertical Rate of Climb (VRC)
4000'/95°F	500 Feet Per Minute (FPM)
2000'/70°F	650 FPM
Sea level/59°F	750 FPM
Airspeed (IRP, 4000'/95°F)	112 knots
Endurance	2.4 hours

Controllable in 35 knot winds from any direction

These performance figures are contractually guaranteed by Bell Helicopter Textron and, therefore, represent only the minimum levels of performance achievable with AHIP. The agility, maneuverability, and stability required in the NOE environment will finally be at the scout pilot's finger tips, improving not only mission performance, but also reducing pilot workload and eliminating numerous accident cause factors.

In order to improve NOE communications, the aircraft will be equipped with two improved FM (IFM) radios, one VHF, one UHF, and full provisions for a HF-SSB radio. The IFM radios will be capable of 40 watts output versus the current 5 watts and have secure voice capability. The UHF and HF-SSB have the capability for secure voice. To further reduce crew workload, the radio controls have been fully integrated to allow operation and frequency selection by the pilot without removing his hands from the flight controls. The NOE communication/navigation improvements will provide necessary aircraft and target location accuracy and facilitate better and more reliable communication between the scout helicopter crew, command elements, and companion aircraft.

To enhance navigation, the aircraft is equipped with a Doppler navigation system and a flight plan display selectable on the MMS display. These systems are fully integrated to give the pilot current position, direction and distance to the next way point and a variety of other required navigational data. The scout pilot and observer will be able to devote their attention to other mission tasks rather than being constantly involved in the process of aircraft navigation.

The modern battlefield will be highly dependent on terminally guided munitions, and the AHIP is ideally suited to not only locate the target but to also provide laser designation for the AAH (HELLFIRE missiles), COPPERHEAD (artillery), and other US Air Force precision guided munitions. Incorporated in the MMS is a laser for ranging and target designation, a TV for daytime imagery, and Forward Looking Infrared (FLIR) for night imagery. The MMS is located above the main rotor to allow the AHIP to acquire and designate targets while masked behind terrain and/or vegetation, thus preventing aircraft exposure to enemy air defense systems.

The navigation, target acquisition and designation, flight instrumentation, and communication systems are all contained in a fully integrated cockpit. Standoff ranges provided by the Mission Equipment Package (MEP), the reduced detectability provided by the MMS, and the ultimate inclusion of the Multipurpose Lightweight Missile (MLM) self protection capability, will enable the AHIP to perform its mission with a significant improvement in survivability.

The logistical supportability of the AHIP will also be improved where possible over the baseline OH-58A aircraft. Airframe performance improvements will be accomplished with the goal of providing the additional mission capability with no degradation in airframe Reliability, Availability, Maintainability (RAM) characteristics. Airframe components requiring redesign to achieve performance requirements will undergo continuing review to insure that RAM considerations are included in the design process. Quantitative RAM requirements will be imposed on newly developed mission equipment including the MMS and will be validated during testing. In addition, extensive reliability growth testing will be performed on the MMS to ensure achievement of RAM requirements.

The program, which does not require technological advancement, will incorporate approximately 56 percent (by weight) of existing or 0 risk hardware and components to include major structural elements, engine and transmissions. The remaining 44 percent, though strictly classified as "new design", is incorporation of existing technology through: (a) scaling of current capabilities to the scout helicopter (e.g., electrical capacity, engine inlet and landing gear sizing, bracketry/wiring/plugs to mount and install new equipment, structure for armament, etc.)--21 percent; (b) modification of existing designs to the specific installation (e.g.,

rotor blades and hub)--11 percent; and (c) repackaging and integration of existing mission equipment capabilities (TV camera, laser, controls, displays, and FLIR),--12 percent.

In summary, the AHIP/NTSH modification program will provide a day/night target acquisition and laser designation capability through incorporation of the MMS into existing OH-58A helicopters. It will also include the integration of improved NOE communication and a doppler navigation system, as well as space, weight, power, and structural provisions for later incorporation of an air-to-air missile system as a self defense capability. Aircraft performance will be improved to provide a minimum acceptable hot day hover capability and an acceptable vertical rate of climb for worldwide deployment. The quantitative and qualitative improvements in scout missions performance provided by the AHIP will enable the scout pilot to at last actually perform those scout missions that have been too long beyond his and/or the aircraft's capability. The net result will be a significant improvement in the effectiveness of the combined arms team on the modern battlefield.

COST DEFINITIONS

This shows the cost I will be discussing these are only the Research and Development Costs as outlined in DA Pam 11-2. It is the dollars controlled by the Project Manager.

The TRACE is "Total Risk Assessing Cost Estimate" which are the funds that can be applied to any of the areas shown to resolve problems as the program evolves.

COST DEFINITION

BASELINE COST DATA FOR RESEARCH AND DEVELOPMENT

- DEVELOPMENT ENGINEERING
- PRODUCTION ENGINEERING AND PLANNING
- TOOLING
- PROTOTYPE
- DATA
- SYSTEM TEST AND EVALUATION
- SYSTEM PROJECT MANAGEMENT
- TRAINING
- OTHER
- TRACE

Table 2–1. Research and Development Cost Elements

Element Number	*Cost Element*
1.0	Research and Development Cost
1.01	Development Engineering
1.02	Producibility Engineering & Planning
1.03	Tooling
1.04	Prototype Manufacturing
1.05	Data
1.06	System Test and Evaluation
1.07	System/Project Management
1.08	Training Services and Equipment
1.09	Facilities
1.10	Other

2-5. Research and Development Cost Element Definitions *a. Research and Development Cost.* The term, "R&D Cost," (1.0) is defined, in general, to be the sum of all costs resulting from applied research, engineering design, analysis, development, test, evaluation and managing development efforts related to a specific materiel system. The term R&D cost includes:

(1) All costs to the Government, defined as contractor costs plus in-house costs, of products and services necessary to bring a specific materiel system from concept to serial production.

(2) All costs to the Government of developing the specific capability, irrespective of how such costs are funded, i.e., irrespective of which appropriations (RDTE, MPA, MCA or OMA) are cited, and irrespective of which organization within the Army has responsibility.

b. Development Engineering (1.01). This element includes the costs incurred during study, analysis, design, development, evaluation, testing, and redesign for the work breakdown structure (WBS) component(s) during the system development effort. It includes the design effort of preparing specifications, engineering drawings, parts lists, wiring diagrams, test planning and scheduling, analysis of test results, data reduction, report preparations and establishment of reliability, maintainability and quality assurance control requirements. It also includes the cost of raw and semifabricated material plus purchased parts consumed in the performance of component engineering effort. Included also are engineering test equipment such as oscilloscopes, transducers, recorders, radio transmitters, converters, discriminators, receivers, and other equipment required to accomplish the engineering function for the specified WBS element. Excluded from this element is the engineering effort (Producibility Engineering, and Planning) to insure producibility of the item or system prior to quantity procurement.

c. Producibility Engineering and Planning (PEP) (1.02). This element includes cost incurred in assuring the producibility of the developmental weapon system, item, or component. PEP involves the engineering tasks necessary to insure timely, efficient and economic production of essential material and is primarily software in nature. PEP includes efforts related to development of the Technical Data Package (TDP), Quality Assurance (QA) plans, and special production processes to assess producibility. Also included are development of unique processes essential to the design and manufacture of the materiel and details of performance ratings, dimensional and tolerance data, manufacturing assembly, sequences, schematics, mechanical and electrical connections, physical characteristics including form, fit and finishes, inspection test and evaluation requirements, calibration information, and quality control procedures.

d. Tooling (1.03). This element includes the planning, design, fabrication, assembly, installation, modification, maintenance and rework of all tools, inspection equipment, and test equipment supporting the development of a specified WBS component. It includes that time expended in determination of tool, inspection, and test equipment requirements; planning of fabrication and testing operations; maintenance of tool records; scheduling and control of all tool orders; and programing and preparation of tapes for all numerically controlled machine tools used in development of a WBS component. It includes the cost of new material used in the fabrication, assembly, installation, modification, maintenance and rework of dies, jigs, fixtures, inspection equipment, handling equipment, work platforms, and test equipment used to develop each WBS component, as well as tools normally purchased in final form or which require negligible effort to assemble.

e. Prototype Manufacturing (Including Spares) (1.04). This element contains the cost of fabrication, processing, subassembly, final assembly, reworking modification, and installation of parts and equipment, power plants, boosters, electronic equipment, explosives, and other items (including Government furnished equipment) and the proving of such equipment and instruments for the specified WBS prototype element. This includes the construction of piece parts from raw materials, the cutting, forming, stretching, and blanking operations performed on material to make individual parts. It includes bench assemblies of all minor and major assemblies, mating or joining of primary sections, installation of special and general equipment, instruments and accessories performed after the mating, and all other preparation and/or processing and preflight and production service operations. Also included are the raw and semifabricated material plus purchased parts used in the manufacture of the specified WBS prototype item. The cost of prototype spare assemblies and parts are also included within this element.

f. Data (1.05). This element includes the cost of preparation, revision, and reproduction of drawings, specifications, parts lists, test plans, testing procedures, draft manuals and other documentation which is produced in support of project management, engineering, tooling fabrication, and testing functions. Relative to a contract, this element includes cost of all deliverable data listed on a DD Form 1423, i.e., such effort as can be reduced or eliminated with reductions or elimination of the listed requirements. If the data are Government peculiar, include the efforts of acquiring, writing, assembling, reproduction, etc. If the data are not Government peculiar, but are identical to that used by the contractor except in a different format, include cost of such efforts as reproduction, packaging, shipping, and, if necessary, reformatting.

g. System Test and Evaluation (1.06). This element contains cost of only system-related development and operational test activities (DT/OT I&II), including cost of specially fabricated hardware to obtain or validate engineering data on the performance of the system. This element also includes cost of the detailed planning, conduct, support, data reduction, and reports from such testing, as well as hardware items which are consumed or planned to be consumed in the conduct of such operations as well as cost of all effort associated with the design and production of models, specimen, fixtures, and instrumentation in support of the test program. The actual test article(s) (i.e., functionally configured systems) are excluded from this element; they were included in element 1.03 (prototype manufacturing). Testing which can be associated with a subsystem (e.g., aircraft engine) are included in the cost of that subsystem, rather than this system oriented cost element.

h. System/Project Management (1.07). This element includes cost of the technical and business management effort expended by both the Government and contractor(s) in the process of developing an integrated system. It contains cost for planning, directing, and controlling the definition, development, and production/testing of the prototype system/project and assuring that planning is accomplished by organizations responsible for the complementary functions of logistics and maintenance support, personnel training, operational testing, activation, or deployment of a system. This is a services cost element for the total system and is not to be confused with management effort that can be specifically associated with subsystem hardware elements; the cost of which is included in the cost of that subsystem/element.

i. Training Services and Equipment (1.08). This element includes costs of services, devices, accessories, aids, equipment, facilities, and parts used to facilitate instructions through which personnel acquire sufficient concepts, skills, and aptitudes to operate and maintain the system with maximum efficiency. This element includes cost of effort associated with the design, development, and production of prototype training equipment, and the execution of training services. It includes the costs of training initial service test crews and maintenance personnel, including TDY of Government personnel, involved in DT/OT I and II.

j. Facilities (1.09). This element includes costs of any new building, conversion or expansion of facilities or sites, and the acquisition of real estate for development and testing of the system. It includes any construction cost for modification and testing of systems already in the Army inventory if necessary to the furtherance of the R&D program.

k. Other (1.10). Any R&D cost not included in the previous elements will be included here and completely identified as to kind and type, i.e., prime contractor general and administrative expenses and profit may be included in this category, if parametric data base does not account for it elsewhere.

2-6. Research and Development Cost Exclusions. Specifically excluded from R&D cost estimates are:

a. Costs incurred during the Investment and Operating and Support phases of a program.

b. Research and Development costs which cannot be directly related to the system itself or which cannot be reasonably allocated to the system. Research (6.1) and Exploratory Development (6.2) categories are not considered to be program peculiar R&D costs.

COST ESTIMATES:

You could see from my discussion of the History of the ASH Aircraft there have been many, many estimates the ones shown here are those just before and after contract award.

The estimates in 1980 were based upon a little simpler aircraft then wound up in the RFP. As you can see the Oct 80 estimate which was made using the draft RFP came very close to the final program cost when the contract was awarded.

It must also be remembered that the R&D contract is a fixed price contract and therefore the cost exposurer to the government is limited.

REASONS FOR DIFFERENCES

The next chart shows what I feel makes up the reasons for the differences. As you can see I feel that the largest reason is changes in statements of work. I feel this is usually the reason the "Cost" grow.

COST ESTIMATES

	JUL 80	AUG 80	OCT 80	AUG 81	AUG 82
ESC	158 - 167	167		230	228
CONST (FY81M)	138 - 145	145	170	169	193

REASONS FOR ESTIMATE DIFFERENCES

- INFLATION INDICES 20%
- CHANGES IN SCHEDULE 10%
- CHANGES IN STATEMENTS OF WORK 70%

LESSON LEARNED

The problem with a lesson learned chart is the once you write down the lessons they seem simple.

The list I have here is anything but simple: The reason I say they are not simple because they require a lot of communication between the Cost and Technical people.

Technical people don't communicate well period, and cost people don't have time. In addition cost drivers are not easy to identify. Usually a cost driver is something you want, (or think you want), or must have. I find, its something better than what we now have, we can identify what we would like to have and don't have in what we got, but are not good at saying its okay that way.

As an example: I own a Ford Escort with a wide ratio standard transmission. Its a good transmission and its fine for my needs it gets me around town and gives good gas mileages <u>but</u> the next escort I will specify the close ratio transmission it costs more plus does not give as good mileage. If the Army owned the thing: some technical guy would be trying to replace all the wide ratio transmissions with close ratio transmissions based upon Human Factors, i.e. reduce noise, plus he would claim an increase in gas mileage. In additon he would propose a development program for an "improve" close ratio transmission. Its that guy you got to find, which means you must know something about aircraft and what makes them expensive.

LESSONS LEARNED

- IDENTIFY COST DRIVERS EARLY-ON
- COMMUNICATE COST DRIVERS TO TECHNICAL PERSONNEL
- KEEP COST DRIVERS OUT OF SOW'S
- TEACH MANAGEMENT A LITTLE ABOUT COST ANALYSIS



ADP001241

16

THE REGRESSION LINE IS ALWAYS LINEAR OR IS IT?

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For: 17th Annual DOD Cost Analysis Symposium

Date: 12-15 September 1982

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ABSTRACT

The Regression Line Is Always Linear,
Or, Is It?

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The paper discusses, illustrates, and contrasts the Multivariable Linear Regression Model with the Multivariable Nonlinear Regression Model. Emphasis is placed upon technique and analysis of the curvilinear function. Identified are a series of procedures and steps to follow in analyzing the data base as a means of curvilinear specification. An example is fully illustrated using first a linear approach and then a nonlinear approach. Results of this example are examined for justification and ultimate logic.

The analysis presented is an overview only with the objective being to review the nonlinear model and encourage creative, reflective analysis of the data base. Numerous resources are listed in the bibliography. An indepth review of these materials will enhance understanding and appreciation of the Nonlinear Modeling technique.

FIGURES

Number	Topic	Source
1	Assumptions	D. L. Harnett
2	Time Series Data	QMT 550 text
3	Curve Function	J. R. Hale
4	Net Scatter Diagram	Analysis
5	Net Scatter Diagram	Analysis
6	Two-Variable Nonlinear Curve Forms	J. R. Hale
7	Nonlinear Residuals	Analysis
8	Nonlinear Residuals	Analysis

FOOTNOTES

Page	Topic	Source
1	Introduction	Wall Street Journal, 25 Mar 82 7 Apr 82
2	Regression Model	D. L. Harnett, Intro to Statistical Methods, 2d Ed., pp. 357-411.
3	Assumptions	D. L. Harnett, p. 365.
4	Time Series Data	QMT 550 text, p. 56.
6	Curve Function	J. R. Hale, Two-Variable Nonlinear Regression, p. 34.
5	Cost Theory	Pappas & Brigham, Managerial Economics; 3d Ed., pp. 305-340.
12	Curve Forms	J. R. Hale, Two-Variable Nonlinear Regression, p. 2.
21	Guide to Multivariable Nonlinear Regression Analysis	J. R. Hale, Multivariable Nonlinear Regression, pp. 147-148.
23	Summary	J. R. Hale, MVNLR, p. 103,131.
24	Summary	J. R. Hale, Two-Variable NLR, p. 44.

The Regression Line is Always Linear, Or, Is It?

Introduction:

Today we find the political as well as societal and economic spotlight firmly focused upon DOD spending activities. Pick up most any issue of the Wall Street Journal and you'll find reference made to the billions of dollars being considered and/or appropriated for DOD programs. Such references are not always made in the most gracious manner; i.e., how do we cost analysts respond to Art Buckwald's satire, "There isn't a man alive who knows what a B-1 bomber is going to cost until he actually makes one." ? or argue with the statement"...the politics of putting defense spending on a rational basis are themselves formidable..." ?

Obviously this emphasis on DOD spending has tremendous impact on estimating activities at the functional level. Ever increasing pressure is experienced as the cost analyst is challenged to identify, quantify, and utilize the most appropriate and refined estimating methodology. While we all recognize the estimating arena as a highly dynamic, pressure intensive environment IN OR OUT of the limelight, we also recognize the need for periodic review of methodology and application. With this need in mind, the purpose of this paper is to provide a brief overview of the linear versus nonlinear regression models.

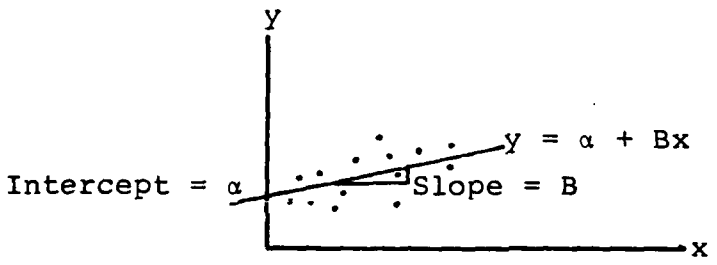
Basic Regression Model:

Briefly defined, regression is ..."the description of the nature of the relationship between two or more variables." Represented mathematically, the Population Regression Model is:

$$yi = \alpha + Bxi + Ei$$

where: x = independent variable(s)
y = dependent variable
α = y-intercept
B = slope of the regression line
E = error term

and graphically where:



and as estimates of the population parameters

where: Sample Regression Line = $Y = a + bx$

Sample Regression Model = $Y_i = a + bX_i + e_i$

The Model uses the ..."method of least squares, a curve-fitting technique in which values of "a" and "b" are derived by finding the sample regression line which provides the best fit to the sample data." In order to make valid inferences from sample data about population relationships, certain assumptions must be satisfied.

Ideally, these assumptions are:

Multiple Variable Linear Regression Model Assumptions

1. The error terms (Ei) are all independent of each of the (m) independent variables where independent variables are X_1, X_2, ..., X_m.

2. The error terms for all possible sets of given values of X_1, X_2, ..., X_m are normally distributed. (See Figure 1)

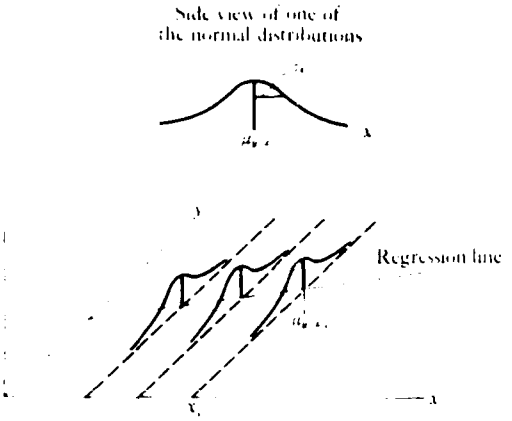


Figure 1

3. The expected value of the error terms is zero for all possible sets of given values of X_1, X_2, ..., X_m.

4. The variance of the error terms is constant for all possible sets of given values X_1, X_2, ..., X_m. When this assumption is met, the data is said to be homoscedastic. When it is violated, the data is said to be heterscedastic.

5. Any two error terms (Ei and Ej) are independent; i.e., their convariance is zero. When this assumption is violated, the data are said to be autocorrelated.

(Note: This assumption of independence is not valid for most time series data. Time series tend to move in cycles rather than randomly about the trend, so that adjoining values; i.e., in two boom years, are closely related. Independent and dependent data are illustrated in Figure 2.)

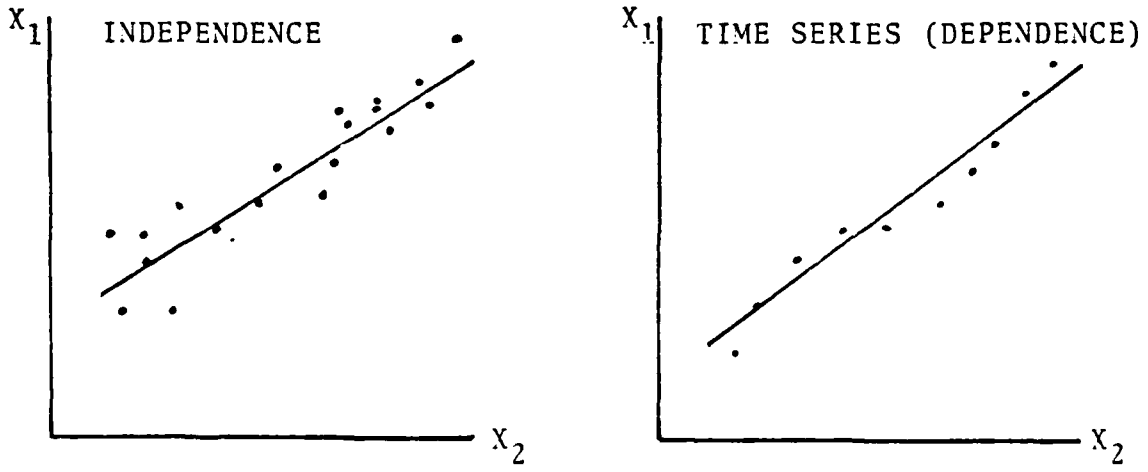


Figure 2

6. None of the independent variables is an exact linear combination of the other independent variables. (Note: This means that no one variable Xi is an exact multiple of any other independent variable... In fact, this is a weak assumption because it requires that the variables not be perfectly related to each other in a linear fashion. In practice, the independent variables are often partially linearly related to each other, or sometimes perfectly related to each other, in some nonlinear way. When two or more of the independent variables are strongly related to one another (but not perfectly), this situation is known as multicolinearity.)

7. The number of observations (n) must exceed the number of independent variables (n) by at least two; i.e., $n \geq m + 2$. (Note: This assumption merely specifies that there be at least one degree of freedom; i.e., $n-(m+1) \geq 1$).

Multivariable Nonlinear Regression Model Assumptions

Looking next at the assmuptions required for the Multiple Variable Nonlinear Regression Model, we find that we will use all of the Linear Model Assumptions plus one additional assumption:

1. The sample data base will be linear in the specified variables; i.e., mathematical transformations will result in linearity of the specified variables.

At first blush, there appears to be very little difference between the assumptions for a linear model and a nonlinear model. In fact, as stated, nonlinearity requires but one additional assumption--linearity of the transformed variables. Yet this one additional assumption allows us to develop far greater refinement in our estimate primarily because this assumption acknowledges that all data sets are not linear. Few would argue with the fact that at some point, costs increase at a faster rate for very small performance improvements. To illustrate, the addition of terrain-following radar to an avionics package while significantly improving performance, may result in even greater increases in cost. The same could be said about improving performance by increased speed. Graphically, a relationship between cost and speed could look like this (See Figure 3).

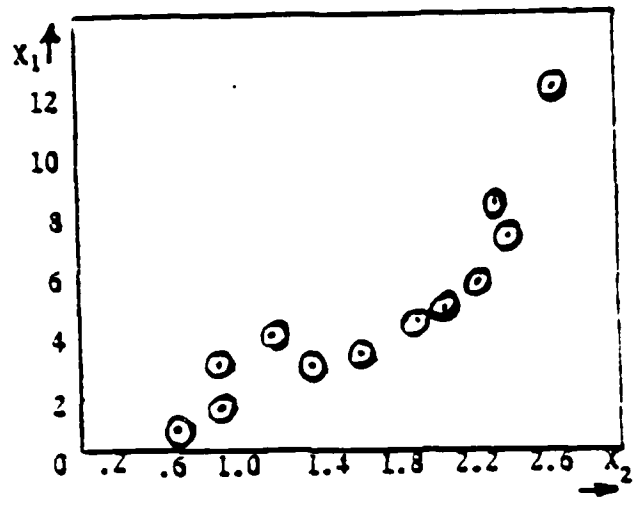


Figure 3

Obviously a linear equation would not be satisfactory; nor would a parabola; but there is some evidence that a cubic pattern exists.

Suggested is that the Cost Analyst not assume linearity but instead test for nonlinearity as well. To illustrate just how the analyst might best do this, the following detailed example is provided. This example is designed to highlight the recommended procedure for examining various data bases. It is not intended to be a panacea, all-encompassing exhaustive checklist of nonlinear versus linear application. It is purely an academic exercise designed to encourage innovative analysis and as such, may be appropriately viewed as a vehicle for identifying fundamental curvilinear function characteristics. Most likely the analyst will wish to tailor this strictly academic approach to something more practical; i.e., provide information regarding known strengths (weaknesses) of various data bases, perceived future trends, and overall confidence in the specific data base

being reviewed. With these thoughts in mind, let's examine a sample data base where we wish to estimate just one element of cost -- Direct Labor.

Example

(1) Our Estimating Data Sample consists of:

One Element of Cost: Direct Labor

with Design Parameters: { Weight = 24,000 lbs; Speed = MACH 2.0 }

For a Buy Quantity: 100 aircraft

(2) Our Historical Data Base is:

A/C Model Number	Dir Labor at Unit 100 (Constant $ in 000)	Weight/Unit (000 lbs)	Speed (MACH)
1	1255.56	12.1	1.23
2	1255.13	13.4	1.51
3	1290.61	12.1	1.17
4	1221.04	8.0	2.00
5	1428.85	18.9	2.08
6	1327.12	8.8	0.92
7	1522.56	34.0	2.00
8	1419.82	14.2	0.95
9	1650.32	30.8	0.85
10	1342.76	6.7	0.85
11	1359.46	14.5	2.00
12	1469.32	18.2	2.27

Based on our knowledge of the independent variables, our

(3) CER Functional Rational is:

Weight -- Labor Costs will increase at a decreasing rate as weight is increased.

Speed -- Labor Costs will increase at an increasing rate as speed is increased.

(4) The Estimating Eqn Variables are:

Independent Variables -- { Weight
                         { Speed

Dependent Variable -- Dir Labor Costs

(5) The Estimating Eqn Characteristics are given by the Multiple Variable Linear Regression Model where:

$$y = a_{1.23} + b_{12.3} X2 + b_{13.2} X3 + e$$

(6) And the Cost Estimate which was developed using the Multi-variable Linear Regression Model is:

(a) Direct Labor Costs = 1236.738 + 13.170(Wt) - 46.16(Speed)

Where: { Weight = 24.0
       { Speed = 2.0

--Evaluated for a point estimate:

$1460.496 = Cost for unit 100

--Calculations to determine the 1st unit value w/79% slope:

where: $Y = AX^b$

$$A(\Sigma X^b_{100} - \Sigma X^b_{99}) = 1460.496$$

1st Unit Value = 6992.80

--To calculate Lot Cost for 100 unit buy

where $A({}^{100}\Sigma X^b)$ = Lot Cost

$215,132.45 = Total Lost Cost

(b) Analysis of the Linear Equation provides these

--Statistical Results:

(1) Total Variation = 174,262

(2) Explained Variations = 132,094

(3) R^2 = 75.8%

(4) F Score = 14.09

(5) Std Error = 68.4

-- Looking at a graphical Display of Residual Values where:

(1) The objective is: Equal distribution of the residuals about the regression line w/no discernable pattern.

(2) And the Procedure is: Develop & plot a Net Scatter Diagram. (Note: See Appendix A for calculation of Net Scatter diagram values.)

(3) Analysis of Residual values reveals:
No discernable pattern for weight (See Figure 4).
Obvious parabolic pattern for speed (See Figure 5).

-- We can now make some conclusions:

(1) Based on our estimating rational for weight, a linear function is incorrect; i.e., our estimating rational states that labor costs will increase at a decreasing rate as weight is increased.

(2) Based on our estimating rational for speed and our net scatter diagram, a linear function is incorrect; i.e., our estimating rational states that labor costs will increase at an increasing rate as speed is increased and our net scatter diagram displayed a pattern.

Net Scatter Diagrams

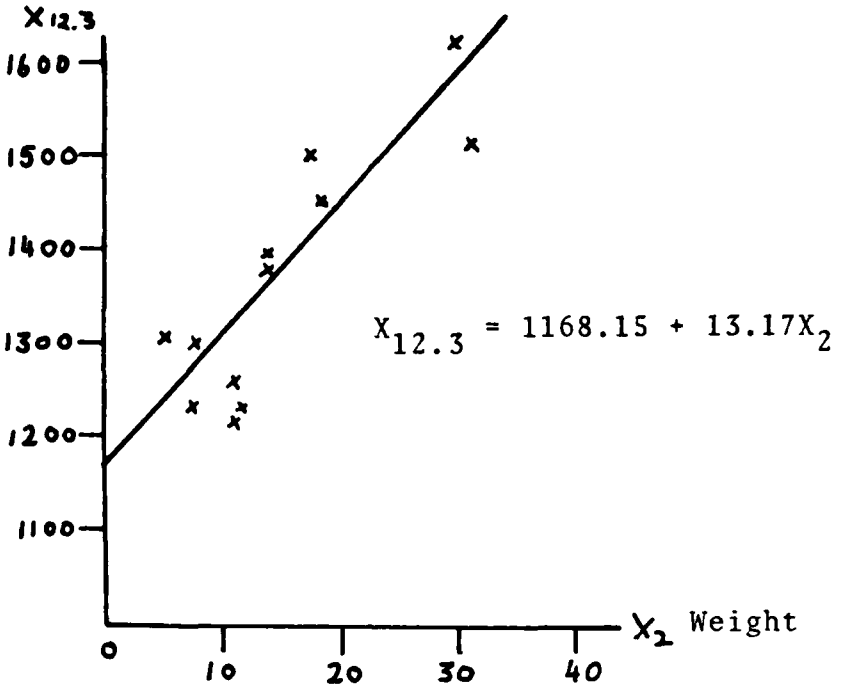


Figure 4

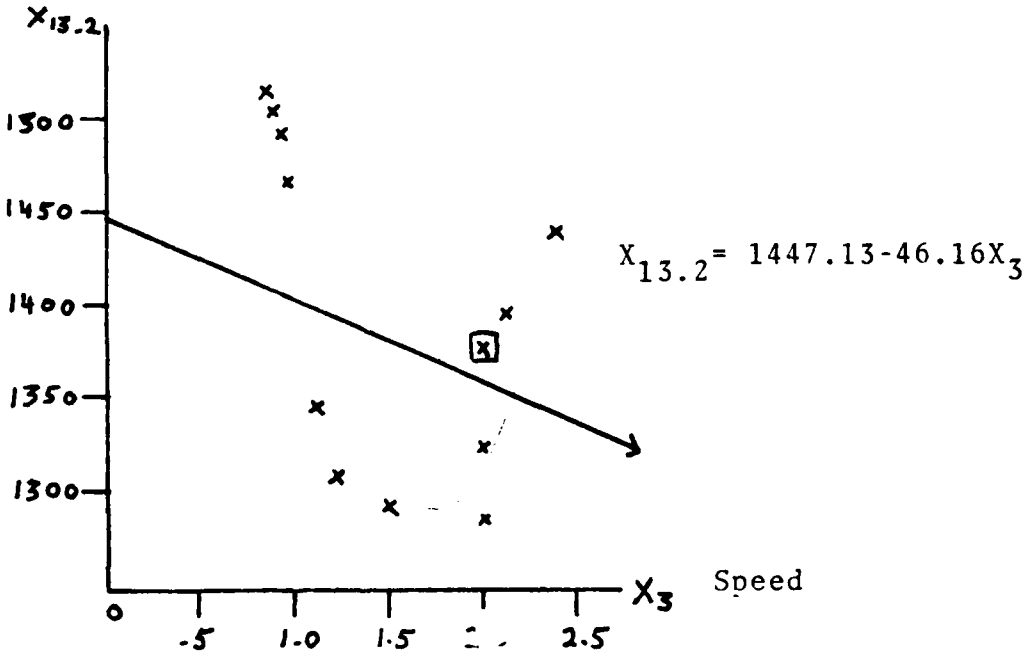


Figure 5

(3) Based on (1) and (2) above, a lot cost of $215,132.45 is questionable. However with this linear analysis, it is not possible to determine whether $215,132.45 may be too high or too low.

(4) Conclude that while the statistical values fall within a generally acceptable range, further analysis suggests that a linear eqn will not generate the most viable lot cost.

(7) So, now let's reconsider the Independent Variables with emphasis on the estimating functional rational.

(a) Based on above analysis (6), the cost estimating curvilinear function will not be linear. Therefore, the function must be nonlinear. A number of nonlinear curvilinear functions are depicted in Figure 6. Considering only those functions which support our estimating rational (weight: increase at decreasing rate; speed: increase at increasing rate), our choices are fairly numerous -- parabola, cubic, hyperbola, and square root, to name a few!

While there are several nonlinear forms which will give results superior to a strictly linear form, for the purposes of this example, a square root formulation for weight and a parabolic formulation for speed has been selected.

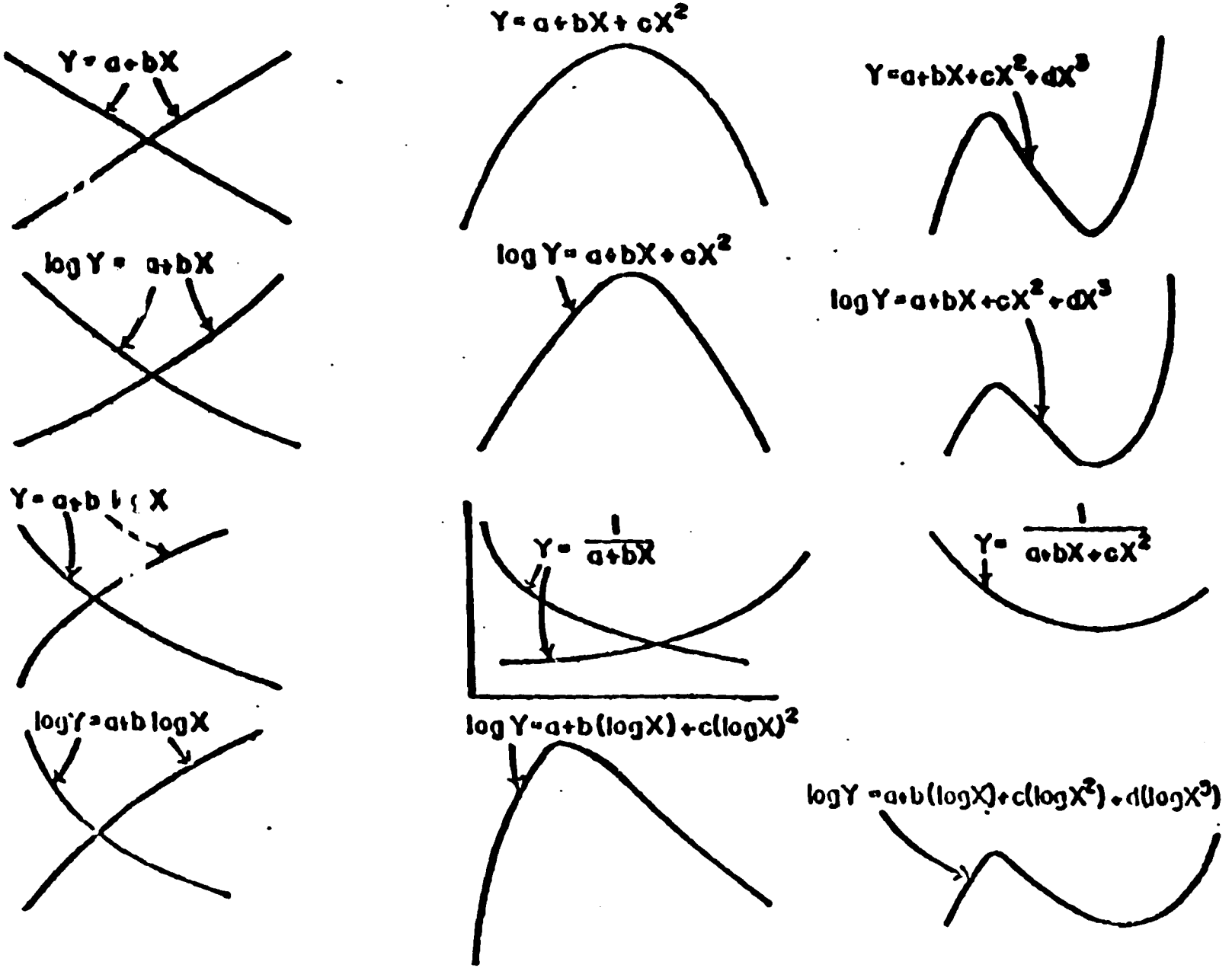
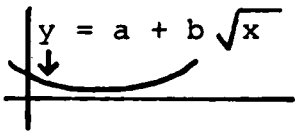

Y = a + bX
Y = a + bX + cX²
Y = a + bX + cX² + dX³
log Y = a + bX
log Y = a + bX + cX²
log Y = a + bX + cX² + dX³
Y = a + b log X
Y = 1/(a + bX)
Y = 1/(a + bX + cX²)
log Y = a + b log X
log Y = a + b(log X) + c(log X)²
log Y = a + b(log X) + c(log X²) + d(log X³)

Figure 6

(b) A general graphical representation of these non-linear functions appear below:

(1) Square Root form:



(2) Parabola form:



(8) Our cost estimate is now developed using a nonlinear Eqn with a square root formulation for weight and a parabolic formulation for speed:

(a) Direct Labor Costs =

$$= 1800.436 + 103.2817\sqrt{\text{weight}} - 1175.018(\text{speed}) + 371.3047(\text{Spd})^2$$

Where $\begin{cases} \text{weight} = 24.0 \\ \text{speed} = 2.0 \end{cases}$

-- Evaluated for a point estimate:

$1441.5927 = Cost for unit 100

-- Calculations to determine the 1st unit value w/79% slope

where: $Y = AX^b$

$$A(X_{100}^6 - X_{99}^b) = 1441.5927$$

1st unit value = 6902.2953

-- To calculate lot cost for 100 unit buy

where: $A\left(\sum_1^{100} X^b\right)$ = Lot Cost

$212,347.98 = Total Lot Cost

(b) Analysis of nonlinear Egn provides these statistical results:

(1) Total Variation = 174,262

(2) Explained Variation = 171,617

(3) R^2 = 98.5%

(4) F Score = 173.03

(5) Std Error = 18.2

-- Again, looking at a graphical Display of Residual Values where:

(1) The objective is: Equal distribution of the residuals about the regression line with no discernable pattern.

(2) And the procedure is: Plot a zero-line scatter diagram.

(3) Analysis of Residual values reveals:

No discernable pattern for weight (See Figure 7).

No discernable pattern for speed (See Figure 8).

-- Conclusions?

(1) So far, so good! We conclude that further analysis of the nonlinear function is appropriate.

-- Essentially, our analysis of the nonlinear forms selected will be structured to insure that t.. functions ultimately support our estimating rational and; additionally, that the equation makes sense (i.e., a parabola has a vertex -- where is the vertex in relation to the data base and the parameter to be estimated?).

(1) To do this analysis, we will use derivatives, graphs, and general knowledge of curvilinear functions where our estimating equation is:

Plot of NonLinear Residuals

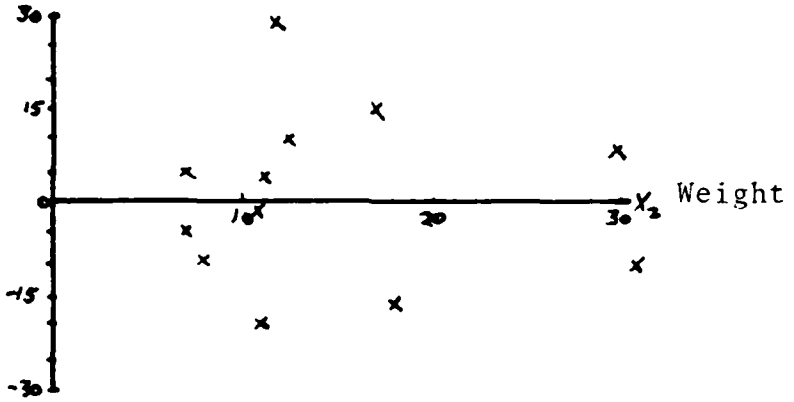


Figure 7

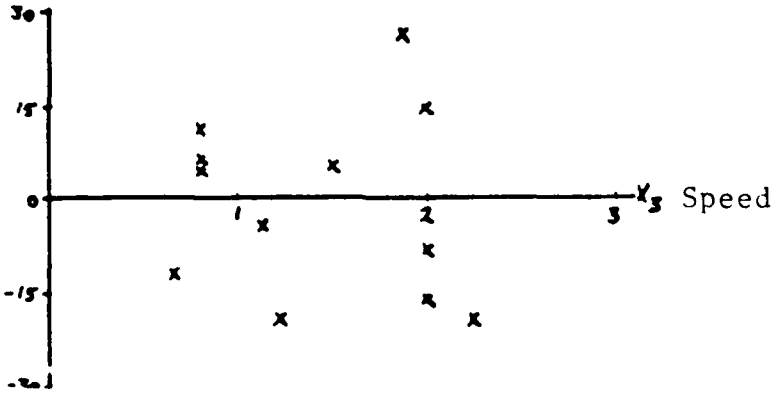


Figure 8

Direct Labor Costs=$1800.436+103.2817\sqrt{\text{Weight}}-1175.018(\text{Spd})+371.3047(\text{Sp})^2$

(a) Weight: Analyzed with 1st and 2d derivatives

(weight = X_2):

$$F(X) = 103.2817\sqrt{X_2}$$

$$= 103.2817\ X_2^{1/2}$$

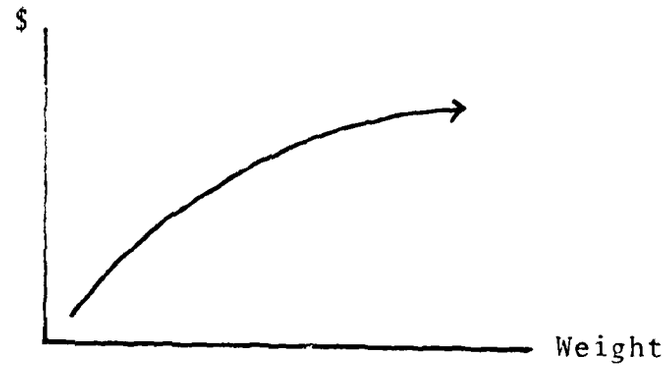
$$F(X)^1 = 1/2\ (103.2817)\ X_2^{1/2-1}$$

$$= 51.64085\ X_2^{-1/2}$$

$$F(X)^{11} = -1/2(51.64085)X_2^{-1/2\ -1}$$

$$= -25.820425X_2^{-3/2}$$

Conclude: When the 1st derivative is > zero and the 2d derivative is < zero, the function is increasing at a decreasing rate. Graphically, the function is:



This function ultimately meets our estimating rational.

(b) Speed: Analyzed with 1st and 2d derivatives (Speed = X_3):

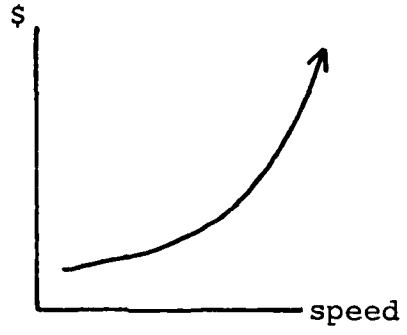
$F(X) = 371.3047X_3^2 - 1175.018X_3 + 1800.436$

$F(\overset{1}{X}) = 2(371.3047)X_3 - 1175.018$

$= 742.6094X_3 - 1175.018$

$F(\overset{11}{X}) = 742.6094$

Conclude: When the 1st derivative is > than zero and the 2d derivative is < zero, the function is increasing at an increasing rate. Graphically, the function is:



(c) Because this is a parabolic function, the location of the vertex must be determined. The location of the vertex is important because for our estimating eqn to make sense, we must be estimating in the 1st Quadrant; i.e., only positive values for speed make sense!

Using the quadratic equation and parts thereof, the vertex is:

$$\text{Vertex} = \frac{-b}{2a} = \frac{-(-1175.018)}{2(371.3047)} = 1.58$$

A vertex of 1.58 falls approximately in the middle ot our data base range and is to the left of the parameter we wish to estimate -- conclude: our equation is still good!

(d) Lastly we are interested in where the parabola crosses the horizontal axis because, again, we must estimate in the 1st Quadrant.

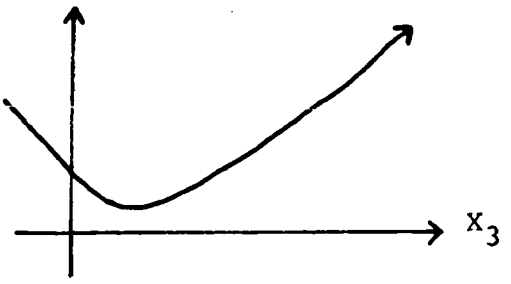
To do this, we will use the discriminant from the Quadratic equation as follows:

$$\text{discriminant} = \sqrt{b^2 - 4ac}$$

$$= \sqrt{(-1175.018)^2 - 4(371.3047)(1800.436)}$$

$$= \sqrt{-1.293,374.095}$$

Since the value of the discriminant is imaginery, the parabola does <u>not</u> cross the horizontal axis. The general shape of our parabola is:



Conclude: Our equation is good statistically and gives logical results!

(e) One additional feature which must be analyzed is multicolinearity where multicollinearity refers to how independent our independent variables truly are. While there are numerous mathematical approaches for determining whether multicollinearity exists, the following has been selected:

$$\text{Test for Multicolinearity} = \frac{(\Sigma X_2 X_3)^2}{(\Sigma X_2^2)(\Sigma X_3^2)} = 6.69\%$$

Using the Coefficient of Determination (R^2) formulation as the indicator of the relationship between the independent variables, conclude: We have a low percentage of multicolinearity. Hence, we can conclude that our independent variables are essentially independent.

(f) Overall Conclusions: Statistically, logically, ultimately, our nonlinear equation is acceptable!

We may now compare the linear equation results with nonlinear equation results:

(a) Linear Equation:

Direct Labor Costs = 1236.738 + 13.170(Weight) = 46.161(Speed)

(b) Nonlinear Equation:

Direct Labor Costs = 1800.436 + 103.2817$\sqrt{\text{Weight}}$ - 1175.018(Speed) + 371.3047(Speed)^2

(c) Statistical Results:

	Linear	Nonlinear
Total Variation	174,262	174,262
Explained Variation	132,094	171,617
R^2	75.8%	98.5%
F Score	14.09	173.03
Standard Error	68.4	18.2

(d) Estimated Costs ($000):

	Linear	Nonlinear
Lot Cost	$215.132.45	$212,347.98
Avg Unit Cost	2,151.32	2,123.48

(e) Conclude:

-- Logically, statistically, and monetarily we obtain better overall results with the nonlinear equation.

The process we go through in working with a Multiple Variable Nonlinear Regression Model obviously requires an indepth appreciation and knowledge of mathematics coupled with statistical analysis. While this process may initially appear cumbersome and lengthy, actually it is neither. To simplify and specify exactly what we have done in our illustration, the following guide is provided.

A Guide to Multivariable Nonlinear Regression Analysis

The first step in this type of analysis is deciding the ground rules and the general shape of the function. Logic must guide the formulation of the ground rules.

1. Symmetry: Is the relation symmetrical?
2. Is the relation monotonic; i.e., does it always go in the same direction, continually increasing or continually decreasing?
3. Is the rate of change constant; does it increase (or decrease) at an increasing (decreasing) rate?
4. Does the relation have an asymptote?

As you may have surmized, we are really establishing the behavior of the function without specifying the function. By combining the above ground rules with a graphical picture of what we know about the relation, we may be able to use these to identify the function. If so, we can then fit a mathematical function.

With the ground rules or logic established, we follow a set pattern:

1. Do a linear regression of the data.
2. Plot net scatter diagrams for each of the independent variables. If the net scatter diagrams give a clear enough picture, draw a function. If not, proceed to Step 3.
3. Group the observations and plot the averages. The objective here is to get enough data points to give a good guide for drawing the function.

4. Using both the logic of the function and the graph from Step 3, draw in a function.

5. It is now possible to identify the function from this curve and use a computer to try a mathematical fit. If this cannot be done, correct the function and then try again!

Upon completion of these ground rules and procedure, the analyst should insure that the mathematical function meets expectations and obeys the logic. An unqualified 'yes' guarantees an acceptable and defensible estimating equation!

Summary -- When to consider using the MVNLR Model:

In working with nonlinear relationships, the analyst should be ..."very familiar with the data." Selection of the appropriate nonlinear functional form requires more than simple statistical analysis -- the analyst must have a hypothesis against which to check assumptions and knowledge of the data being analyzed..." Logic and knowledge of the world should tell us that certain relationships are important and how they should behave, then mathematical skill will tell us what functional forms behave in this fashion. Statistical analysis can then be employed to determine whether or not the data will support the hypothesis suggested by logic. An analyst should have, as tools of the trade, a fair idea of the forms various functions tend to take on net scatter diagrams. There is one article of faith that should be accepted: statistical functions do not look exactly like those of the mathematical functions. A cubic relation will almost never display those characteristics that distinguish it from a parabolic; the domain over which the relative maxima and minima occur is too narrow to be detected by a scatter diagram. Our statistical tools are simply not sensitive enough to reveal unsuspected critical points. If the critical points are to be detected we must have the idea they are there and be looking for them!

Acknowledging that ..."the cost analyst's problem is almost never to get a good fit; his problem is to get reasonable predictions or justifications. If, for example, one fits linear equations when the relations are in fact square roots there is a tendency

to over-estimate at the extremes and underestimate in the middle areas." ..."There is simply no guaranteed result that any chosen function is the true function. Selecting logical functions and then making comparisons of goodness of fit, including tests of significance, helps in making a choice. However, we must go beyond just statistical comparison. Logic must dictate the statistical acceptability. The best choice is one which meets the qualifications of statistical acceptability and the tests of logic."

In summary, the analyst must:

(1) be familiar with the characteristics of the various formulae:

(2) be familiar with the behavior of the elements with which she is working; i.e., knowing the slope should be negative, or that it should be nonlinear or asymptotic to a lower limit;

(3) be able to get expert advise from those who know;

(4) be able to fit the data statistically to verify or reject the formulations suggested by logic.

Conclusion:

The fully-illustrated example along with cautions and recommendations for using the Multivariable Nonlinear Regression Model has been presented primarily as a refresher. While we all recognize this as a technique with which the cost analyst has long been familiar, we also recognize this as a technique which can easily be overlooked in preference for the linear regression model. Obviously when the data base is linear, the linear regression model is the model to use. However, let's not resort to use of the linear model out of habit -- let's insure that our analysis has at least considered the nonlinear model also and that we make our model selection appropriate to the data base.

The illustration presented is an overview only. More detailed information may be found by referencing the sources identified in the Bibliography. The resource information has been derived primarily from the AFIT Advanced Cost Estimating coursework, QMT 550 and 551, where one can obtain indepth training in the nonlinear techniques.

Appendix A

```
READY
RUN

READY
RUN


AND ARE YOU USING STORED PROGRAMS

ENTER NAME OF FILE CONTAINING STORED DATA(FILE#)

FILE NOT SAVED  FILE#

LINE  CALLING-FUNCTION

READY
RUN

 ENTER NO. OF USED VARIABLES
 ENTER NAME OF FILE CONTAINING STORED DATA(FILE#)
```

DO YOU NEED SUMS OF SQUARES AND CROSS PRODUCTS?YES

ROW 1
1.000000E-01 4.657143E-01 1.751000E-01 2.950510E-01
1.674E-04

ROW 2
4.657143E-01 1.917000E-02 7.876537E-01 1.200631E-02
5.810E-04

ROW 3
1.751000E-01 7.876537E-01 2.980510E-01 5.446571E-01
2.457676E-04

ROW 4
2.950510E-01 1.200631E-02 5.446571E-01 1.051000E-02
4.110E-04

ROW 5 SSQ = 2.677692E+07
DO YOU NEED VAR AND COVAR.MATRIX?YES

VARIATIONS TOTAL 1.244444E-05 EXPLAINED, 1.216172E-05
UNEXPLAINED 2.827222E-07

VARIABLES EXPLAINED 5.710571E-04 UNEXPLAINED 5.000611E-02
STD ERROR 1.000000E-01 DW 1.810000E-02 PSCORE 1.000000E-02

X(I)	VAR EXPLAINED BY X(I)	VAR NOT EXPLAINED BY X(I)	STD ERROR OF B(I)
2	1.000000E-05	3.000000E-02	5.000000E-00
3	4.000000E-04	1.000000E-02	1.000000E-02
4	3.000000E-04	1.000000E-02	3.000000E-01

IF DEP VARL - ENTER

f	0
[illegible] f	1
[illegible] f	[illegible]0

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Appendix B

Net Scatter Diagrams:

Objective: To identify any pattern in the diagram which can be used to specify a curvilinear function.

Procedure: The steps in plotting a net scatter diagram are:

1. Do a linear regression of the data.
2. Calculate a $_{liy}$ or intercepts.
3. Draw net regression line.
4. Using residual values from computer printout, plot residual at appropriate independent value using net scatter regression line as a base; i.e., residuals with positive values will be plotted <u>above</u> the regression line and those with negative values will be plotted <u>below</u> the regression line.

Calculations for Direct Labor Costs:

1. Linear eqn = $1236.78\% + 13.17028X_2 - 46.16116X_3$

   where X_2 = weight @ 24.0

   X_3 = Speed @ 2.0

   $\bar{X}_1 = 1378.5458$

   $\bar{X}_2 = 15.975$

   $\bar{X}_3 = 1.4858$

2. Intercepts:

   Weight = $(a_{12.3} = \bar{X}, - b_{12.3}\ \bar{X}_2)$

   $= 1378.5458 - 13.1702\%(15.975)$

   $= 1168.150577$

   eqn $X_{12.3}$ $= 1168.150577 + 13.17028X_2$

$$\text{Intercepts} = \begin{cases} X_2 = 0, & X_{12.3} = 1168.15 \\ X_2 = 35, & X_{12.3} = 1629.110377 \end{cases}$$

(b) $\text{Speed} = (a_{13.2} = \bar{X}_1 - b_{13.2}\,\bar{X}_3)$

$$= 1378.5458 - (-46.16116)(1.4858)$$

$$= 1447.132052$$

$$\text{Egn } X_{13.2} = 1447.132052 + (-46.16116)X_3$$

$$\text{Intercepts} \begin{cases} X_3 = 0, & X_{13.2} = 1447.13 \\ X_3 = 2.5, & X_{13.2} = 1331.729 \end{cases}$$

3. See Figures 4 and 5 for graphs of Net Scatter Diagrams.

4.

Residuals	Weight	Speed
-83.7	12.1	1.23
-88.4	13.4	1.51
-51.5	12.1	1.17
-28.7	8.0	2.00
39.2	18.9	2.08
16.9	8.8	0.92
-69.6	34.0	2.00
39.9	14.2	0.95
47.2	30.8	0.85
57.0	6.7	0.85
24.1	14.5	2.00
97.7	18.2	2.27

Note: Plotting the residuals can be seen by looking at the graph for speed (Figure 5) and data item Number 11 where Speed = 2.00 and Residual - 24.1. The plotting of this point is located by finding 2.00 on the horizor al axis and then locating the

residual value of +24.1 at approximately +24.1 ABOVE the regression line (For reference purposes, this point is boxed on Figure 5).

BIBLIOGRAPHY

J. R. Hale, Multivariable Nonlinear Regression, February 1982 Version, 100 pps.

J. R. Hale & R. D. Kankey, Two-Variable Nonlinear Regression; July 1979, 55 pps.

D. L. Harnett, Introduction to Statistical Methods; 2d. Ed., Addison & Wesley 1977, 551 pps.

Pappas & Brigham, Managerial Economics; 3d Ed., Dryden Press 1979, 656 pps.

AFIT, Advanced Quantitative Methods, QMT 550, Vol I, 97 pps.

The Wall Street Journal, 25 Mar 82 & 7 Apr 82.

AD P001242

TIME SERIES ANALYSIS

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Somewhere between the simplicity of univariate statistics and the complexities of regression lies the group of estimating techniques used in time series analysis. They range in difficulty from very simple, to fairly complex. All are based upon forecasting using a trend or pattern over time. This article addresses some of the concerns and questions about the use of time series analysis and covers some of the simpler, but useful techniques.

To begin, time series analysis techniques are not deterministic techniques. Unlike regression, they do not reflect a causing relationship. Instead, they all take advantage of a pattern over time. In time series analysis, it is recognized that there are many causing variables. If we expect their magnitudes and effects to remain, we can accept that the net effect of all those variables can be summarized by the changing pattern of cost over time. We thus use time as a stand-in for all the causing variables. We believe that future costs can be predicted based on the pattern formed by past costs.

When this sort of pattern over time has developed, and we believe that all the causing variables will continue to exert the same forces and move along their same paths, then time series analysis techniques provide an excellent alternative for the analyst.

Before using any technique, the analyst needs to have a feel for the situation being estimated. In time series, a critical question is, "Will the trend continue, or will the trend change?" If the analyst feels it will continue, a stable technique should be used. If the trend is likely to change, a responsive technique should be used. The trade off is that a responsive technique reacts more strongly to the expected random variation in costs, resulting in forecasts that "jump around" even if the trend does not change.

Another decision has to be made on what portion of the cost history is appropriate. Graphing the data over time may indicate that the trend has changed in the past. After determining why the trend changed and the likelihood of such changes in the future, the appropriate most recent portion of the data is selected.

Now, what kinds of patterns are possible? The possible patterns (without considering changes in the pattern) include no-trend, linear trend, non-linear trend, and cyclic trend. A no-trend pattern is clearly possible over time. In this case, time series may be of limited value in estimating the future. A graph with this type of pattern looks like Figure 1.

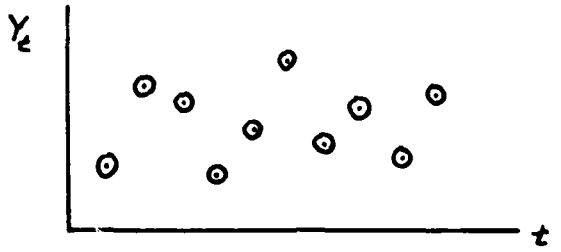


Figure 1: A No Trend Situation

Here we have random variation but an underlying constant value. Time series techniques to forecast under this situation include use of the mean, single moving averages, moving weighted averages, and single exponential smoothing.

A linear trend pattern indicates an underlying linear pattern over time and is illustrated in Figure 2.

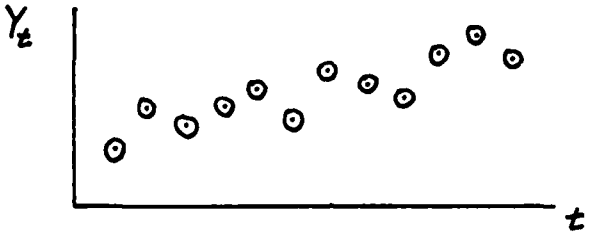


Figure 2: A Linear Trend Situation

If we had experienced such a linear trend in the past and expected it to continue, we would use a linear trend technique such as a least squares best fit line, double moving averages, or double exponential smoothing.

If we had been experiencing a non-linear pattern over time, illustrated in Figure 3, we again have several choices.

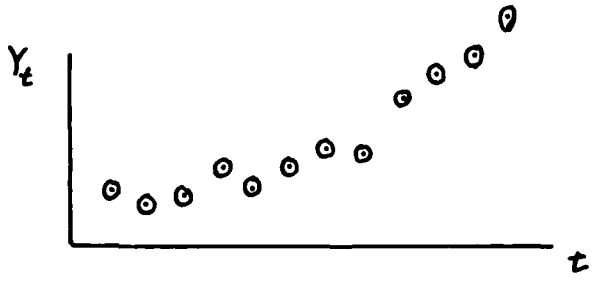
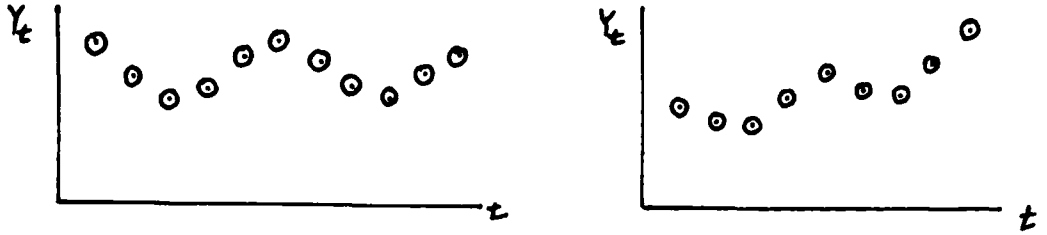


Figure 3: Non-Linear Trend

We can use a linear trend technique and attempt to adjust for the bias (i.e., add or subtract the expected error), or we can use transformations and best fit a non-linear curve to the data. Other choices include more complicated time series approaches, such as triple exponential smoothing, which are beyond the scope of this paper.

Another possible pattern over time is the cyclic pattern, shown in Figure 4:



Cyclic with no trend Cyclic with trend

Figure 4

In some cases costs will vary over time. For example, seasonal adjustments are made to many government indices and fuel consumption rates (gal/hr) in aircraft vary over the year with higher consumption in hot months and lower consumption in cold. To address this cyclic problem, we can change all the data to cycle-length averages and always forecast an average. This effectively smooths the variations over the cycle. Other, more complicated techniques, are also beyond the scope of this paper.

Now for a brief discussion of some of the basic time series analysis techniques. These basic techniques are those designed for use in no-trend and in linear trend cases. The decision as to whether a no-trend, or a linear trend technique should be used is based upon which type of pattern exists. A look at the data over time may indicate a clear pattern, or it may not. If not, Spearman's Rank test will provide an answer as to which type technique would be more appropriate.

NO TREND

If a no-trend technique is desired and a stable situation exists, then a technique is to forecast future costs as the mean of past costs. If this is felt to be too stable, or not responsive enough, then a single moving average can be used. With single moving averages, the forecast is always the average of the last n data points. The n can be made larger or smaller, depending upon whether more stability or more responsiveness is desired. Using this technique, only the last n data points contribute to the forecast. Each time a new period rolls around and a new data point is developed, an old point is dropped. An embellishment on this technique is the idea of weighted moving averages. Here the analyst has some additional knowledge that the last n data points should not be evenly weighted. For some reason, certain data points should carry more weight than others. A typical weighting procedure would give more weight to the most current data. One procedure, when weighting is felt to be appropriate but no apriori weights are known, is to use the sum of digits approach. This approach for assigning weights says that if we are using n data points we first find $1+2+\ldots+n = k$. We then assign weights. The most recent receives a weight of n/k, the next most recent receives a weight of $\frac{n-1}{k}$,... and the oldest a weight of $\frac{1}{k}$. Single moving averages and moving weighted averages are both very easy techniques to understand and use.

A last no-trend technique is called single exponential smoothing. Here, as in each of the previous techniques, a new forecast is made each time period. This technique is similar to the weighted moving average approach but uses a very systematic weighting scheme. In a sense, the single exponential average builds from an assumed starting value and weights each new point with the following procedure:

$$E1\ (c,t) = cY_t + (1-c)\ E1\ (c,t-1)$$

where E1 indicates a single exponential average and E1 (c,t) indicates the single exponential average with a smoothing constant c made at time t.

Y_t is the cost for time period t

E1 (c,t-1) is the previous single exponential average.

It is thus clear that we must start with an assumed exponential average for time t=o and we never throw any data away. It stays in the calculator but is given less and less weight as t gets larger. Two ways to start the process are to let E1 (c,o) = Y_1 or $\bar{Y}$. The preferred method is to use $\bar{Y}$ for the data that is available when you decide to start. Once started, the process is iterative. You do not recalculate E1(c,o) as more data accumulates.

Since c, the smoothing constant, is vital to the process, it's appropriate to look at its characteristics. Its value is bounded by zero and one. Normally the c value is greater than zero and less than .5. The larger the c, the more responsive the technique, the smaller the c, the more stable. It is thus necessary for the analyst to decide whether the pattern is expected to stay the same or change so that an appropriate c can be chosen.

No-trend techniques thus vary from very stable techniques to techniques which can be adjusted for more or less stability/responsiveness. In general, these techniques are designed to be iterated easily as we move through time. All no-trend techniques forecast the future at our current average cost.

LINEAR TREND

If we have a linear trend pattern, than our alternatives include the LSBF line using all the data, double moving averages and double exponential smoothing. The LSBF line uses all the (appropriate) data and is relatively stable. Its forecasts will not be greatly affected by either random variation in the new data point, or a change in trend. It is thus, once again, necessary for the analyst to decide whether the trend is expected to continue or change before choosing a technique. If LSBF is felt to be too stable, i.e., not responsive enough, then another technique should be used.

Double moving averages is a linear trend technique that allows adjustment for more or less stability. The technique uses the following formulas:

$$M1(n,t) = \frac{Y_t + Y_{t-1} + \ldots + Y_{t-n-1}}{n}$$

$$M2(n,t) = \frac{M1(n,t) + M1(n,t-1) + \ldots + M1(n,t-n+1)}{n}$$

M1 (n,t) Single Moving Average at Time t

Y_t The Cost at Time t

M2(n,t) Double Moving Average at Time t

The single and double moving average is calculated for each time period t when data is available. The n is consistent for both and is the number of data points used in each average. Larger n's result in more stable forecasting, smaller n's make the technique more responsive. When using this linear trend technique the forecast is in the form of a straight line ray with this ray used to forecast future costs. The forecast equation made at time t for the future involves a_t and a b_t where:

$$a_t = [2\ M1(n,t)] - M2(n,t)$$

$$b_t = \frac{2}{n-1}\ [M1(n,t) - M2\ (n,t)]$$

The forecasting equation is then

$$FM2(n,t,t+i) = a_t + b_t * i$$

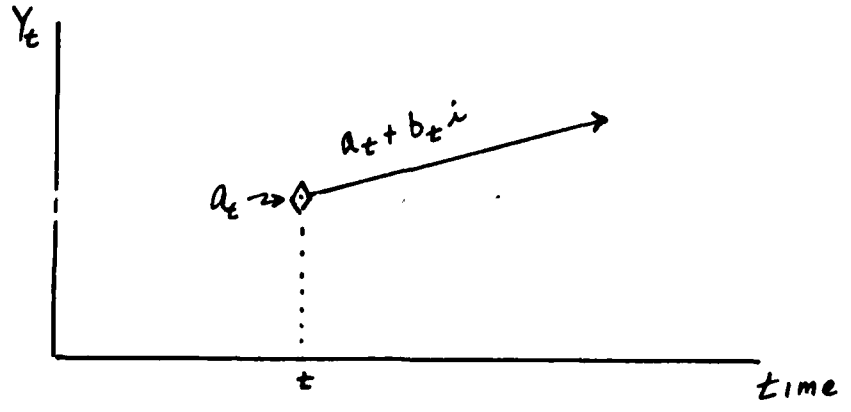
FM2 Our forecast using double moving averages

n The number of items averaged

t The time period when the forecast is made

i The numbers of periods ahead for the forecast (the forecast interval)

If we graph this ray we have:



The data points used for a double moving average forecast are the last 2n-1 points.

Another linear trend technique is double exponential smoothing. This technique is an expansion of the single exponential smoothing and likewise uses a very systematic weighting process. The double exponential average is:

$$E2(c,t) = cE1(c,t) + (1-c)\ E2(c,t-1)$$

While the single exponential average remains:

$$E1(c,t) = cY_t + (1-c)\ E1(c,t-1)$$

and:

E2 indicates a double exponential average

E1 indicates a single exponential average

t indicates the time period when the averages are made

c indicates the smoothing constant

Y_t indicates the cost at time t

This process is very easy to iterate. For example, if we find that the cost for time 101 was 44, we can iterate from the data:

t	Y_t	E1(.2,t)	E2(.2,t)
100	40	38	36
101	44		

To get the new single and double exponential averages:

$$E1(.2,101) = (.2)(44) + (.8)(38) = 39.2$$

$$E2(.2,101) = (.2)(39.2) + (.8)(36) = 36.64$$

Since this is a linear trend technique, we will once again be forecasting costs on a ray defined by a_t and b_t where they are now defined as:

$$a_t = 2E1\ (c,t) - E2\ (c,t)$$

$$b_t = \frac{c}{1-c}\ (E1(c,t) - E2(c,t))$$

Our forecast equation for periods ahead is:

$$FE2\ (c,t,t-i) = a_t + b_t\ *i$$

If we use the example's data to forecast 4 periods ahead:

$$a_{101} = 2(39.2) - 36.64 = 41.76$$

$$b_{101} = \frac{.2}{.8}(39.2 - 36.64) = .64$$

$$FE2\ (.2,101,105) = 41.76 + .64 * 4 = 44.32$$

The technique of using exponential averages to forecast costs is called exponential smoothing.

One point on double exponential smoothing that should be discussed is "How do we start?" As shown, each exponential average is a weighted average of all prior data. How did we calculate an E1 (c,0) and E2(c,0) so that the iterative process can begin? The recommended procedure is to do a LSBF on the data available when you want to start the process. Set your regression equation $a = a_t$ and $b = b_t$, then work the formulas in reverse to solve for an E1(c,0) and E2(c,0).[t] Note that since we are now in a linear trend situation , the continued use of $\bar{Y}$ as our first E1(c,0) would be illogical. Some will, however, indicate that how you start is not critical since the process that assigns weights will assign less and less weight to that assumed value. Exponential smoothing is a child of the computer age. It is easy to iterate but it assumes a reasonable amount of data, say 15 data points (more or less data needed depending upon the smoothing constant chosen).

SELECTING A TECHNIQUE

Now, how do we evaluate the forecasting ability of a particular technique in a particular case. We do not have any probability assumptions and cannot compare F tests or Prediction Intervals. What we can do is evaluate how well the technique as performed in the past. To do this we make forecasts for previous time periods and compare those forecasts with the actual reported costs. Since we do not expect such forecasts to exactly equal the costs we need to evaluate the errors.

The most useful measure of these errors is the Mean Absolute Deviation (MAD)

$$MAD = \frac{\sum_{terms} |ERRORS|}{\text{Number of Terms Considered}} \quad \text{or the average of the absolute errors.}$$

If the MAD is 2.13, we can say that on average the technique's forecasts are off by 2.13 units. In general, a technique with a smaller MAD, based on past (simulated) forecasting would be seen as a better choice to forecast the future; if the technique is acceptable in terms of stability and responsiveness.

No technique is always useful, that is why the analyst needs to know several different techniques. Time series techniques are simpler to use than regression techniques and help fill the gap between statistics and regression. If a time series technique is appropriate and gives satisfactory results, it should be used.

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Applied Research in Statistics - Mathematics - Operations Research

VALIDATION OF THE COST METHODOLOGIES WITHIN THE WEAPON SYSTEMS SUPPORT COST SYSTEM (D160) OF THE AIR FORCE VAMOSC SYSTEM

by

Dennis E. Smith

(Presented at the 17th Annual DOD Cost Analysis Symposium)

September 1982

Prepared under Air Force Contract No. F33600-80-C-0554

Abstract

The Air Force VAMOSC system has been mandated by DOD to aid in decision-making for modification and acquisition of weapons systems. VAMOSC data will be used in cost models that support decisions to obligate billions of dollars. Therefore, the accuracy of VAMOSC's output and the validity of its logic are paramount to the utility of the system to the user. For this reason, the Air Force Office of VAMOSC is relying on independent contractors to validate the VAMOSC logic and data sources. This paper discusses aspects of an ongoing research effort by Desmatics, Inc. to validate the Weapon Systems Support Cost (D160) subsystem of the Air Force VAMOSC.

Introduction

In 1975 Department of Defense Management by Objective MBO 9-2 directed each service to provide the means for identifying and providing visibility of the operating and support (O&S) costs of its major weapons systems. The vehicle for accomplishing this objective is referred to as the Visibility and Management of Operating and Support Costs (VAMOSC) program. Through this program, the Air Force developed its VAMOSC system, a comprehensive management information system.

The Air Force VAMOSC system is designed to collect and display O&S costs at MDS (Mission-Design-Series) and component levels of aircraft and also at TMS (Type-Model-Series) and component levels of ground communications-electronics equipment. It consists of three subsystems:

(1) WSSC (D160), which deals with aircraft,

(2) C-E (D160A), which deals with ground communications-electronics equipment,

and (3) CSCS (D160B), which deals with subsystems and components.

Because the data provided by VAMOSC will be used to support decisions involving large financial commitments, the accuracy of this data and the validity of the VAMOSC logic are of prime importance. Desmatics, Inc., under Air Force Contract No. F33600-80-C-0554, is currently engaged in a technical effort to validate the WSSC subsystem of VAMOSC. This paper addresses that validation effort. Although the paper focuses on WSSC, the general concepts are also applicable to the other two VAMOSC subsystems. Because the validation effort is ongoing, any conclusions in this paper must be regarded as preliminary.

The WSSC Subsystem

WSSC produces two annual reports which list O&S costs for each MDS. These reports, which differ primarily in format, are termed the "DOD/CAIG report" and the "USAF detail report." The former report is designed to satisfy the requirements specified by the DOD Cost Analysis Improvement Group (CAIG)[1]. The latter report provides additional details that are useful to various users within the Air Force. Other special interrogation reports are available by MDS, command, and base.

A major problem faced by WSSC is that most available cost data is not identified directly to an MDS. Most of the data sources used by WSSC are functional data systems that do not relate consumption of resources to weapons systems. Of course, in the case of indirect costs, such as installation support costs, there is no way to identify them by MDS.

Because of the lack of a one-to-one relationship between costs and MDS, much of the cost data must be allocated. It is necessary for WSSC to allocate not only the typical "overhead" types of costs, but also direct costs which the input data systems do not identify by MDS. WSSC uses a series of algorithms that relate functional costs to measures of activity in order to allocate the costs to the weapons systems.

In WSSC four general quantities are used to distribute costs: (a) personnel strengths; (b) the inventory of a particular MDS as measured by possessed hours[2]; (c) the number of flying hours for a particular MDS; and

[1] "Aircraft Operating and Support Cost Development Guide," Cost Analysis Improvement Group, Office of the Secretary of Defense, 1980.

[2] An aircraft may be "possessed" by different commands or bases during the year. Thus, the 8760 hours in the year are used to determine the inventory of an MDS for each command and base during the year.

(d) reported maintenance direct labor hours. In addition, estimated cost factors (such as annual medical care costs per person) are used in cost allocation.

Validation of WSSC: An Overview

The reports produced by WSSC serve as an important management tool for providing visibility of weapons systems operating and support costs. The extent to which WSSC cost outputs are satisfactory for their intended purpose depends upon two components: (1) the soundness of system design and (2) the accuracy of input data. The accuracy of VAMOSC's output and the validity of its logic are paramount to the utility of the system to the user. For this reason, the Air Force Office of VAMOSC is relying on independent contractors to validate the VAMOSC logic and data sources.

The overall validation of the WSSC system may be viewed as the three-phase process indicated in Figure 1:

(1) Phase I focuses on the allocation algorithms and data selection logic comprising WSSC,

(2) Phase II addresses the accuracy of the WSSC inputs relative to the books of original entry,

and (3) Phase III examines the accuracy of the books of original entry relative to what actually occurred.

Phase I validation, which addresses the system design, is Desmatics' task under its Air Force contract. Actually, Phase I validation concerns itself with two types of validation: internal validation and external validation. Often internal validation is referred to as "verification," i.e., verifying that the system performs as it was designed. Thus, internal validation primarily involves debugging of the associated computer programs. Similarly, external validation is often referred to simply as "validation," and addresses whether the system is designed as it should be. External

VALIDATION OF THE WSSC SYSTEM

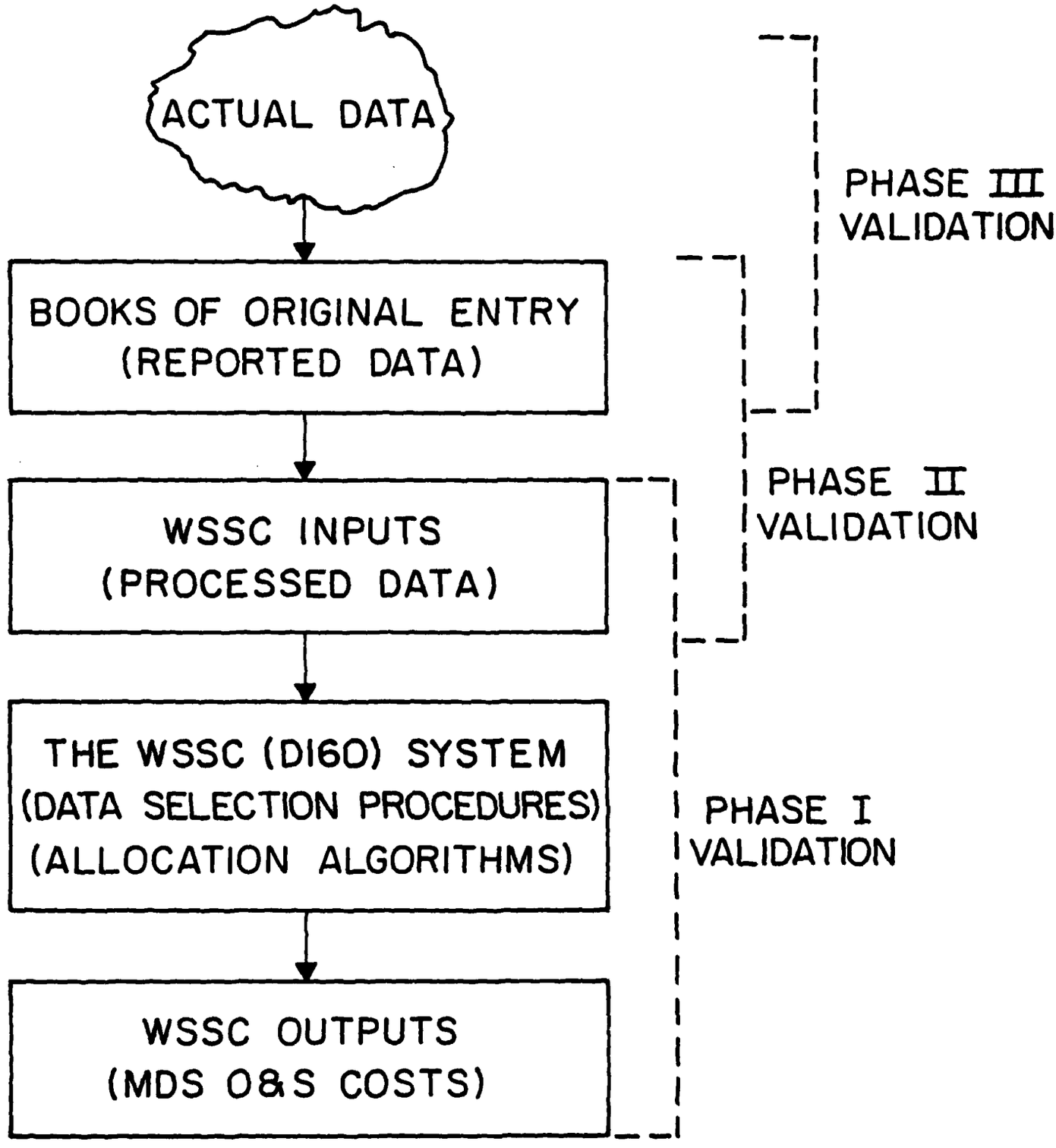


Figure 1: The Three-Phase Validation Process

validation critically examines system logic, input data selection procedures, and output data.

For the most part, internal validation has been accomplished by the Office of VAMOSC in its production test of WSSC. Thus, Desmatics is primarily concerned with external validation. It should be stressed, however, that the overall validation task consists of a large degree of interaction and cooperation between Desmatics and the Office of VAMOSC. This synergistic relationship has had a positive impact on the WSSC system.

Indirect Validation

The best method of validation is, of course, a direct one--that is, one in which the WSSC cost allocations are compared with the true costs. Unfortunately, there is no way to validate the WSSC system directly, because the true costs are unknown. Thus, any validation must be of an indirect nature.

Indirect validation approaches may be classified as dealing with two major types of validity: (1) face validity and (2) mathematical validity. The former is concerned with qualitative assessment, while the latter deals with quantitative assessment. Our validation of WSSC addresses both of these validity components.

Face validity, in essence, is the examination of the WSSC system on a subjective, common-sense basis. In conducting this qualitative assessment of WSSC, Desmatics focused on whether the algorithms provide equitable allocations, so that no group of MDS's bears an inordinate amount of the allocated costs. Somewhat related was consideration of the allocation framework to determine whether alternative allocation methods might provide better results.

A major check on face validity is to determine whether potential users have any suggestions for modifications to the system. Because such suggestions often result in major improvements, the Office of VAMOSC has worked closely with potential users of WSSC during its development.

In parallel with qualitative face validity, Desmatics is also examining the WSSC system from a quantitative standpoint. This involves evaluation of the mathematical framework of the system (including assessment of the allocation logic), consideration of algorithm sensitivity, and examination of pos-

sible data discrepancies. The following sections provide a brief discussion of some aspects of the ongoing quantitative evaluation.

Sensitivity Analysis

A number of FY81 costs within WSSC were allocated on the basis of flying hours (FH) and possessed hours (PH), combined into an allocation ratio. However, just how FH and PH should be weighted within that ratio is an open question. To determine the impact the weighting has on the resulting cost allocations, a sensitivity analysis may be conducted within each cost category which uses flying hours and possessed hours as allocation variables.

Sensitivity of the WSSC results may be examined at different levels of allocation. For example, WSSC not only allocates costs to the MDS level, but also to the command-base-MDS level. Of course, the amount allocated to a particular MDS is equal to the sum of the amounts allocated to all command-base-MDS combinations involving that particular MDS.

In the cases involving allocation ratios based on FH and PH, sensitivity can be measured by examining the differences in allocated costs that result from using only flying hours as opposed to using only possessed hours. There are three measures that may prove useful in assessing the sensitivity of the cost allocations to the use of flying hours, possessed hours, or a mixture of both. One is an absolute measure; the other two are relative measures.

Consider a specific O&S cost category for which costs are allocated by means of an allocation ratio involving flying hours (FH) and possessed hours (PH). Regardless of the level of allocation, we can define

$$\text{Absolute Sensitivity} = \Delta\$ = \$(\text{FH only}) - \$(\text{PH only}). \quad (1)$$

That is, we are measuring the change in dollar amount (either positive or

negative) that would result from using only flying hours as an allocation basis instead of using only possessed hours. If, for example, we are considering the command-base-MDS level allocation, we would have a set of 435 sensitivity observations since there is a total of 435 command-base-MDS combinations.

In addition to (1), two relative sensitivity measures provide useful information. These are:

$$\text{Relative Sensitivity \#1} = \Delta\$/\text{Total Cost Category \$}$$

and

$$\text{Relative Sensitivity \#2} = \Delta\$/\text{Total O\&S \$}$$

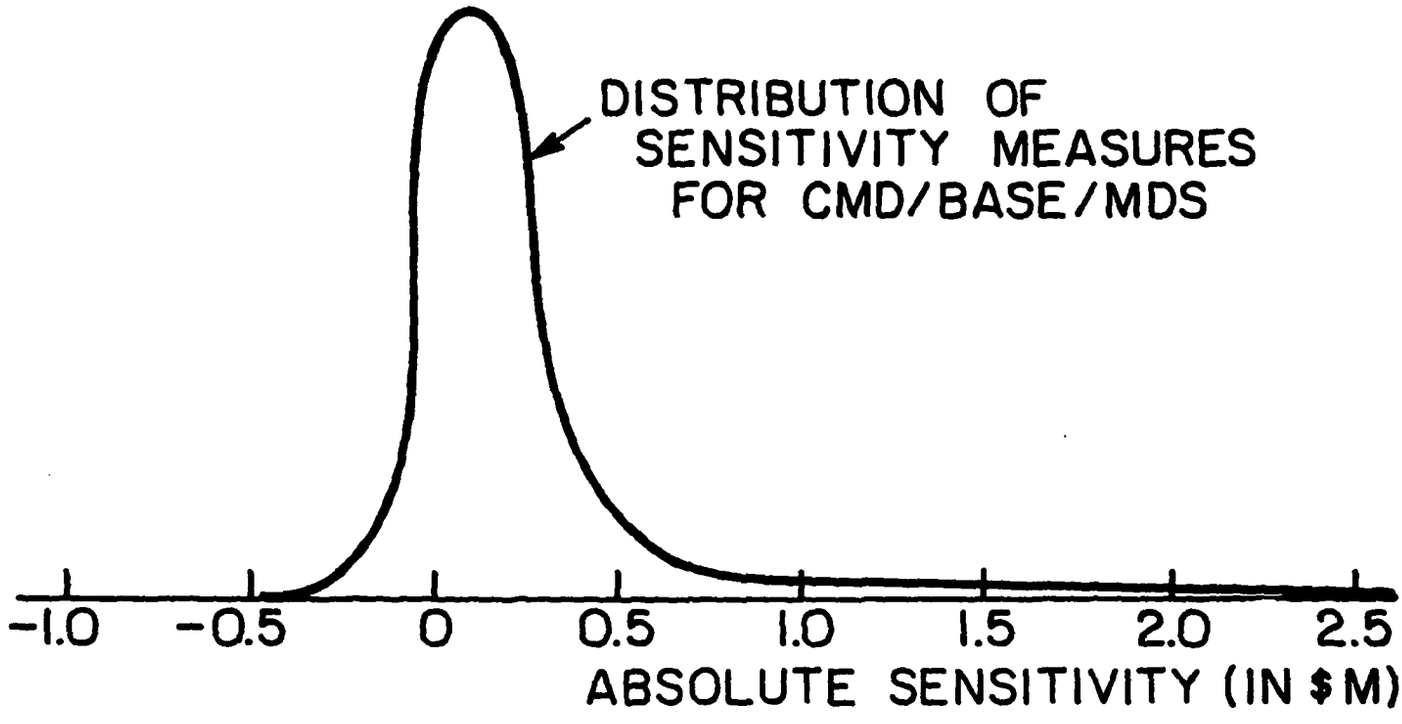
Measure #1 yields an indication of sensitivity of the measures for one command-base-MDS observation relative to the total cost category dollars to be allocated, while measure #2 provides a similar indication relative to the total O&S amount for all command-base-MDS combinations.

As an example, Figure 2 presents, for the general depot support cost category, the distribution of the observed absolute sensitivity measures for each of the 435 command-base-MDS combinations. As can be seen, the distribution is highly skewed to the right, which indicates that a number of command-base-MDS combinations will be allocated a relatively large additional amount of general depot support costs as weighting in the allocation ratio shifts from possessed hours to flying hours.

The maximum observed value in this set of data is \$2.56M. Relative to the total general depot costs of \$246.1M and to total O&S costs of \$11,048.8M, this is 1.04% and 0.02%, respectively.

Results such as these, which provide absolute and relative differences in cost allocations, may be used in conjunction with the results from other

SENSITIVITY (GENERAL DEPOT SUPPORT)



MAXIMUM SENSITIVITY MEASURE:

$2.56M (ABSOLUTE)

1.04% (RELATIVE #1)

0.02% (RELATIVE #2)

Figure 2: Distribution of Absolute Sensitivity Measures for General Depot Support Costs

cost categories to examine the overall sensitivity of cost allocations to the use of flying hours versus possessed hours. Based on this examination, a judgment may be made about the criticality of determining the most appropriate weighting of flying hours and possessed hours. If the overall sensitivity were relatively small, for example, a "ball-park" estimate of the weighting might suffice. However, if the sensitivity were quite large, further investment of effort aimed at homing in on the optimal weighting might be indicated.

Examination of Apparent Discrepancies

To provide a quantitative check on the WSSC results, a number of statistical procedures can be used, including, of course, the calculation of summary statistics such as means and standard deviations. Often graphical presentations are helpful in indicating where there are possible problems within the WSSC logic, because "a picture is worth a thousand words" (or numbers).

Figure 3 depicts a simplified, somewhat diagrammatic, plot of one component of installation support costs (RPM airman pay and allowances) at a base against the number of supported people at that base. Each observation in the plot represents one base. As can be seen, there are a few suspicious data points: data point A and the clump of data points labeled B. Outliers such as these provide a strong indication that something is wrong somewhere.

In this case, it has been determined that the existence of data point A reveals a problem with the input data that must be taken into account by WSSC. Within the Alaskan Air Command, all installation support costs for its three bases are reported in the accounting system at only one base (Elmendorf), while the strengths are reported to the appropriate bases. Thus, the Flmendorf installation costs appear much out of line relative to the base population. In tracking down the second apparent discrepancy, it turned out that data clump B is explained by the fact that these five bases are ones at which depots are located, and a larger share of RPM at depots is done by civilians.

EXAMINATION OF DATA DISCREPANCIES

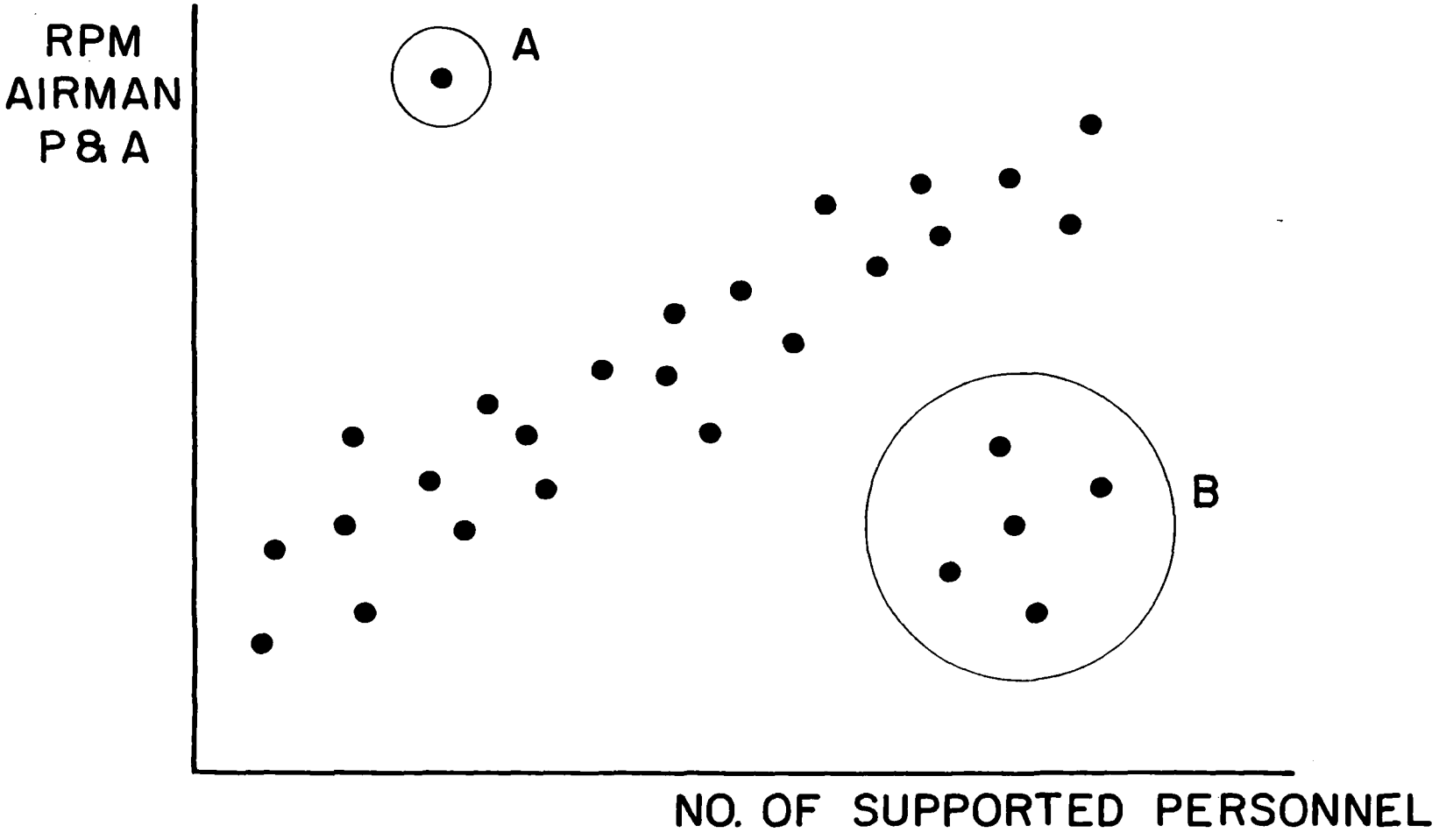


Figure 3: A Diagrammatic Data Plot

Summary

This paper has provided a brief discussion of the WSSC system validation, concentrating on the current research of Desmatics, Inc. That research effort, which deals with Phase I validation, extends through September 1983. Because there is no way in which to validate WSSC directly, Desmatics is using an indirect approach comprised of a qualitative assessment (face validity) and a quantitative assessment (mathematical validity).

To date, the major portion of the Desmatics work has concentrated on the qualitative evaluation and on setting up the framework for the quantitative evaluation effort. Although this paper has discussed some aspects of the quantitative evaluation, a major portion of that evaluation will be completed after the FY82 WSSC data becomes available early in 1983. Nonetheless, a number of recommendations have already been made. For example, Desmatics has suggested:

(1) investigating the application of regression techniques to separate fixed and variable costs in certain cost categories,

(2) replacing allocations based on flying hours and possessed hours with ones based on personnel strength ratios in some algorithms,

(3) revising some personnel strength allocation ratios to make them more appropriate,

(4) providing separate reporting of direct and overhead maintenance costs,

and (5) using a one-stage allocation as opposed to a two-stage allocation in some algorithms.

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VISIBILITY AND MANAGEMENT OF OPERATING AND SUPPORT COSTS

A PRACTICAL APPROACH TO O&S COSTING

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This paper is a brief description of the United States Air Force Visibility and Management of Operating and Support Costs (VAMOSC) development. This paper will define the system, show VAMOSC's objectives, and briefly trace its history. Then the regulations and directives that bound VAMOSC will be discussed. Finally, its output, utility to the customer community, and enhancements will be stated. In the second part of the paper, an example of the use of VAMOSC in the development of an analogy model for operating and support (O&S) cost will be demonstrated and its utility discussed.

Life Cycle Cost is defined as the total cost to the government of acquisition and ownership of a weapons system over its entire life. It includes the cost of development, acquisition, operations and support, and where applicable, disposition (3:86). Some techniques have been developed to estimate the research, development and acquisition costs of new weapon systems, but the operating & support component of the Life Cycle Cost has been more difficult to capture.

The difficulty in estimating operating & support costs for new weapons systems was not a serious problem, while their magnitude was small in comparison to total expenditures. However, in the mid-1960s, it was noted by elements of the DOD that the percentage of total financial resources consumed by O&S was increasing rapidly and soon would surpass the percentage available for acquisition of new weapon systems. Taken to its logical conclusion, the DOD would be ultimately expending all its available resources in supporting existing weapons systems and would have no funds to develop new ones. In 1968, the O&S portion of the total cost of weapon systems exceeded 50% (3:29-30). And inasmuch as the measurement of O&S costs were difficult and inaccurate, then the realization that their magnitude was increasing and would soon become critical, was not readily apparent.

When these facts were finally realized in the DOD, action was taken. In October 1975, the Assistant Secretary of Defense promulgated a Management by Objective (MBO)

9 with the stated goal of reducing operating and support (O&S) costs. A subset of MBO 9 was MBO 9-2 which is titled DOD Requirements for Visibility and Management of Support Costs. This memorandum is the genesis of the DOD VAMOSC development. The guidance tasked the military departments to (1) develop weapons systems operating and support cost visibility, (2) develop component level cost visibility, (3) standardize O&S cost terminology and definitions DOD-wide, and (4) institutionalize the O&S cost systems at each service (1).

The MBO 9-2 guidance to the services pointed out historically that DOD components did not consider the O&S costs as a major decision element in the design, development, and procurement of a new weapon system. The MBO further states that:

> . . . the decision to buy a new weapon system implicitly commits the DOD to support the weapons system over its operating lifetime. In all likelihood, the costs of this support will - for major systems - exceed the initial cost of acquisition. Thus from the viewpoint of the total cost impact on DOD, it is clear that . . . operating and support costs of current systems be identified and examined with a view toward controlling the costs of new systems entering the operating inventory and providing a baseline for hard decisions on affordability and operation and support concepts (1:1).

VAMOSC provides for the user the visibility of O&S costs; that is, "The attribution of operating and support costs to the weapon system for which the costs were incurred and the ready availability of this information to all levels of management (1)." VAMOSC provides this visibility of O&S costs so that others may manage them and reduce and control system life cycle costs

Following the DOD guidance, the Air Force developed two systems to track O&S costs. The first, developed in 1976, was called the Operating and Support Cost Estimating Reference (OSCER). It tracked and reported aircraft O&S costs at the MDS level and was developed by HQ USAF/ACMC. About the same time, HQ USAF/LEYE developed [illegible] a similar system to report O&S costs for Communications, Electronics and [illegible]gical (CEM) equipment at the TMS level; entitled Communications-Electronics [illegible]pport Costs Management Program. Both systems operated in accordance with

their design specifications, however, rapid development had resulted in sketchy documentation and only minimum provisions for configuration management. This allowed the feeder systems to alter their logic without the possibility of reclama from either OSCER or the CEM system. Finally, both systems were allotted only minimum resources for development. These factors caused OSCER's logic to rely heavily on canned utility routines which necessitated much human interaction to operate the system work and an incomplete understanding of the maintenance of CEM's logic when it was transferred from the contractor to the Air Force. Regardless of the many innovative ideas and dedication of the developers of these systems, the factors mentioned adversely affected the operation and utility. Considering the resources available and the deadlines imposed, the talent and dedication of developers was not sufficient to overcome the basic problems (4:4).

Also in 1967, HQ AFLC had developed the Logistics Support Cost Ranking System, K051, which tracked the O&S costs of components of aircraft at the national stock number (NSN) level. However, the system provided only the depot maintenance or exchangeable repair cost of the NSN. A study by HQ AFLC/LOL on line replacement units/shop replacement units (LRU/SRU) led to the enhancement of the K051 system to field level O&S costs by VAMOSC. However, depots deal with costs of reparable items using a stock number identification, bases use work unit codes to track base maintenance. In order to collect the O&S cost of components of aircraft, a national stock number/work unit code cross reference dictionary would have to be developed.

So, the current Air Force VAMOSC operation consists of three data systems to satisfy the CAIG guidance.

a. Weapons System Support Cost (WSSC), D160 data system - O&S costs of aircraft at the MDS level.

b. Communications-Electronics (C-E), D160A data system - O&S costs of ground based communication/electronics systems at the TMS level of detail.

c. Component Support Cost System (CSCS), D160B data system - O&S cost of components of aircraft at the NSN/WUC level of detail.

The requirement for VAMOSC was first promulgated by the MBO 9-2 from DOD. This requirement has been definitized in several other DOD and Air Force regulations including DODD 5000.4, 5000.39, 5000.28, and AFR 800-8.

DODD 5000.4 is titled OSD Cost Analysis Improvement Group (CAIG). "The CAIG acts as the principal advisory body to the DSARC on matters relating to cost (13)." The CAIG also developed and released to the services the Aircraft Operating and Support Cost Development Guide, known as the CAIG Guide. This document provides for the service VAMOSCs' cost definition, excluded costs, and a schedule of accounts for portrayal of costs to DOD (16). This document has been used by the Air Force Office of VAMOSC as a primary requirements document. The D160 and D160A data systems are, in large part, a reflection of this guidance. The CAIG also provides encouragement and cross communication to the service VAMOSCs. This is accomplished by the VAMOSC Steering Committee. This committee, chaired by Dr John Morgan, has members from the Army, Navy, and Air Force VAMOSC organizations as well as HQ and Secretariate level representation.

DODD 5000.39 is titled Acquisition and Management of Integrated Logistic Support for Systems and Equipment.

> The support costs, manpower requirements, and R&M of current comparable equipment shall be identified at a system and subsystem level by milestone I to provide comparative baselines for estimates of new system and to identify and set targets for improvement in the new system.
>
> The heads of DOD components shall . . . maintain reporting systems and data bases, consistent with the provisions of DOD Directive 5000.19 for maintenance data, supply data, deployment, readiness, and utilization data and SA and O&S cost data on

> fielded systems. This data shall be used in DOD Component Visibility and Management of O&S Cost (VAMOSC) Information Systems and made available to developers of new weapon systems at the level of detail needed for design tradeoffs.
>
> The chain of OSD cost analysis improvement group (CAIG) shall issue guidance for . . . service programs to improve support cost estimating techniques and data bases (15).

It is currently being revised and is in draft form as of July 1982. The underscored portion is added and shows the O&S cost data tracked by the service components will be performed by the service VAMOSC organizations.

DODD 5000.28, Design to Cost. It states in part, "Programs to strengthen the data base of weapon system operation and support cost shall continue. As the ability to translate O&S cost elements into 'design to' requirements improves, design to cost goals may be extended into this area (14)." Our ability to meet the intent of this DOD regulation historically has been made more difficult by our lack of O&S cost visibility.

AFR 800-8, Integrated Logistics Support Program. Within the DSARC process for acquiring new weapon systems, certain data is required at each major milestone. The O&S cost estimates for the new system are required early in the process. As the regulation states:

> Program managers and the DPMLs or ILSMs will use maturing data bases and information systems to compare operating and support costs of selected analogous systems as a baseline with proposed systems.
>
> Under attachment 2 - support considerations in the system acquisition process
>
> Milestone 0 - plans for analysis of manpower, other support costs, and readiness drivers of current systems.
>
> Milestone I - manpower and other logistics cost drivers of current systems have been identified at a detail level and targets for improvement on the new systems have been established (12).

The Air Force VAMOSC will provide the actual, historical cost of the components of Air Force systems so that bottoms-up analogy cost models may be built by the System Program Offices (SPO).

The uses for information generated by the VAMOSC system fall into eight major categories. These categories are the result of a series of analyses and do not necessarily reflect a current end product of VAMOSC. However, they will use VAMOSC data as a basis for the analyses described below.

a. Force/Support Program Balance. In building the Five Year Defense Program (FYDP), a balance of funding decisions must be made between force modernization and the operation & support of current forces. The magnitude of the operations and support costs of new system can be more realistically predicted if historical records of current costs are available.

b. Weapon System Comparisons. Credible estimates of the O&S cost impact of new systems and historical perspective of the O&S costs of current systems will permit DOD to better discriminate between competing systems and the costs of the mix of systems to be operated by defense.

c. Support Resource Planning. A key use of O&S cost data is for support resource planning and programming. By establishing a system to accumulate incurred O&S costs by weapon system and undertaking the task of identifying the cause and effect relationships between weapon system design and O&S costs, the services and OSD will be better able to defend to the DSARC and the Congress, the operations, maintenance and personnel support resource demands of new systems.

d. Design Trade Studies to Set Reliability and Maintainability (R&M) Goals. Operating and support cost data can be used in making decisions between alternatives at the subsystem and component levels of weapon systems. Maintenance cost for subsystems related to R&M characteristics will provide a basis for these comparisons.

e. Logistic Support Alternatives. A weapon system cost visibility system can assist in determining the most efficient level (organization, intermediate and depot maintenance) at which to accomplish the repairs by providing historical cost data which can be related to a Service's Logistics concept.

f. Affordability Studies. The determination of new system Life Cycle Costs may indicate that a weapon system, though highly effective in achieving its mission is not practical because of its high cost of acquisition and/or operation and support. The combination of a knowledge of actual weapon system O&S coupled with estimates of downstream cost impacts of new and current systems will permit DOD to make credible system affordability studies. In this light, VAMOSC data can be utilized as a data base to be used with numerous modeling techniques used for O&S cost predictions.

g. Warranty/Contractor Support Analysis. Estimates of current government costs for repair of comparable equipment are necessary to evaluate contractor warranty proposals. Source selection between contractors imposes similar requirements. Historical data on which to base warranty estimates should make them more realistic.

h. Equipment Maintenance Management. Maintenance requirements are peculiar to and therefore, must be determined for each weapon system. Historical data indicating the type, frequency and magnitude of repairs to components of a weapon system are essential to revision of maintenance programs for existing systems. For new systems/subsystem/components, initial maintenance programs could be established and costs predicted based on actual experience with an existing similar system (5:6).

As has been stated above, there are three data systems in the current Air Force VAMOSC. The first is the Weapons System Support Cost (WSSC) system. It provides to the user the O&S cost of aircraft weapon systems. Its cost categories are as follows in the format for the DOD CAIG.

a. Unit Mission Personnel
   Aircrew

d. Sustaining Investment
   Reparable Spares

Maintenance
Organizational/Intermediate
Ordnance
Other Maint. Personnel
Other Unit Personnel
Unit Staff
Security
Remaining Unit Personnel

b. Unit Consumption
Petroleum, Oil & Lubricants
Maintenance Materiel
Training Ordnance

c. Depot Maintenance
Airframe Rework
Engine Rework
Component Repair
Support Equipment
Modifications*
Other Depot
Contracted Unit Spt*
Replacement Support Equip*
Modification Kits

e. Installation Support Personnel
Base Operating Support
Real Property Management
Base Communications

f. Indirect Personnel Support
Misc Operating and Maint.
Permanent Change of Station*
Medical

g. Depot Non-Maintenance
General Depot Support
Second Destination Transportation*

h. Personnel Acquisition & Training* (9)

For the cost categories marked with an asterisk, WSSC either does not currently have a methodology developed, or the costs in the category are mixed with another cost category.

The second VAMOSC system is the Communications-Electronics (C-E) cost system. It provides the O&S cost of ground-based communications-electronics system at the TMS level. Its cost categories are as follows:

a. Installation Support
Base Operating Support
Real Property Maintenance
Communications
Medical (Health Care)

b. Indirect Personnel Cost
Misc Operations & Maint (TDY)
Permanent Change of Station

c. Depot Non-Maintenance
General Depot Support
Engineering Support (Contractor)*
Transportation and Packaging

d. Advanced Training*

e. Operating & Support Cost-TMS Total
Unit Mission Personnel
Operations Personnel*
Base Maintenance Personnel
Unit Administrative Personnel
Supply Support Personnel
Unit Level Consumption
Fuel
Maintenance Material
Utilities
Depot Level Maintenance
Replacement Investment (10)

The cost categories of advanced training, contractor engineering support, and operation personnel are not as yet reported in the C-E system.

The third data system within VAMOSC is the Component Support Cost System, which provides the O&S cost of the components of aircraft at the five digit work unit code and/or NSN. Following are the cost categories reported by CSCS:

a. Base TCTO Costs
   TCTO Labor Costs
   TCTO Material Costs

b. Base Sup Gen Costs by Two Digit WUC

c. Base Labor Costs

d. Base Direct Material Costs

e. Base Maint OH Costs

f. Second Dest. Trans Costs

g. Base Exch Repair Costs

h. Base Exch Modif Costs

i. Base Condemnations Spares Costs

j. Base Sup. Mgmt OH Costs

k. Depot TCTO Costs
   TCTO Labor Costs
   TCTO Material Cost

l. Depot Sup Gen Costs

m. Depot Labor Costs

n. Depot Direct Mat Costs

o. Depot Maint OH Costs

p. Depot Exch Repair Costs

q. Depot Exch Modif Costs

r. Depot Condemnation Spares Costs (11)

WSSC & C-E are top-down systems. If an analyst needs the cost of the aircraft, but not its bits and pieces, then WSSC is the data source. If, however, he is interested only in a portion of the aircraft, say a portion of the radio, which is installed in several aircraft, then he would get his information from the CSCS system. It should be noted when comparing WSSC to CSCS, that WSSC includes more indirect, overhead, and general and administrative (G&A) costs than CSCS. To illustrate, if an airman is assigned to an F-15 squadron's base maintenance activity and must be there because the aircraft are there, then the WSSC system assigns his entire pay and allowances to the F-15. CSCS, however, only costs a portion of his pay when he actually performs and documents via the Maintenance Data Collection System (MDCS) work on the aircraft. So the total base

labor cost for the F-15s using total WSSC vs CSCS, the CSCS will show only direct labor dollars, not indirect and idle time.

The VAMOSC staff early on understood that since the output was to be used, in part, to justify the procurement of new weapons systems via the DSARC process and the modification of existing weapon systems via the POM process, its credibility and veracity must be of the highest. And since this data will be used to help justify the expenditure of billions of dollars, VAMOSC's acceptability by the House and Senate Armed Services Committee and Congressional Budget Office is paramount. Because of this high level of use, the Office of VAMOSC embarked on a contractor validation of the validity of the algorithms, accuracy, and appropriateness of the data sources and utility of the outputs to the user community. This research into VAMOSC's data systems is planned as a three phase approach.

a. Phase I for each system is intended to validate the initial logic, data sources in a preliminary way, and satisfaction of the CAIG requirements. We currently have Phase I contracts for all three VAMOSC systems.

b. Phase II research is to be utilized to validate logic developed after Initial Operational Capability (IOC). This additional logic may be added for any of four reasons:

1. Results of research which repudiates certain algorithms or data sources.

2. Logic developed after IOC to meet the initial requirements, that is, those "too hard" processes such as second destination transportation.

3. A change in input data systems that requires a logic change in order to accommodate it.

4. A new requirement which causes additional logic to be developed.

Phase II research is also planned for each system in order to validate the accuracy of our major feeder data systems. It is planned to let a competitive contract for the DI60 WSSC data system in FY83 and for C-E and CSCS in FY84.

c. The third phase of research is planned for two purposes. The first purpose is to perform longitudinal research for critical, high cost driver algorithms from VAMOSC back to book of original origin. The second purpose is repetitive research on those critical cost elements whose assumptions, constraints, or limitations may change over time and will need to be revalidated periodically (6)..

In this portion of the paper, I wish to discuss more detail as to the utility of VAMOSC to the user via an example. But first, it should be pointed out that WSSC and the other modules of VAMOSC are a cost collecting system, rather than a cost accounting system or a cost estimating system. A cost accounting system accounts for each and every cost to its fullest extent. It performs this function in order to compare total appropriations to total expenditures and to account for any variance. The VAMOSC logic is not interested in all expressions of cost, only weapon system-related costs. Therefore, many costs are excluded. A cost estimating system draws from a population a suitable sample of data and uses it to extrapolate from the sample to a population parameter. Instead of this sampling technique, VAMOSC collects census data in most cases in order to measure population parameters directly rather than through indirect methods. It is for these two reasons that VAMOSC could be entitled a cost collecting system (7:7).

Several data systems feed information into the VAMOSC system. Certain inputs cannot be obtained through the data systems and are, therefore, placed manually into the system via standard reports control system (RCS) reports. It should be noted that the information portrayed in the VAMOSC reports will only be as accurate as the data systems that are feeding the VAMOSC data base (4). And as mentioned above, the Office of VAMOSC is embarked on a multi-year effort to validate the accuracy of the systems input data. VAMOSC has memorandums of agreement (MOAs) with 34 Air Force data systems to provide tapes as well as over 60 RCS reports for manual input of data. VAMOSC originates as raw data at Air Force bases and depots. We collect activity levels such as:

flying hours

base/depot maintenance man-hours

base/depot maintenance material

petroleum, oil and lubricants (POL) consumed

base not reparable this station (NRTS)

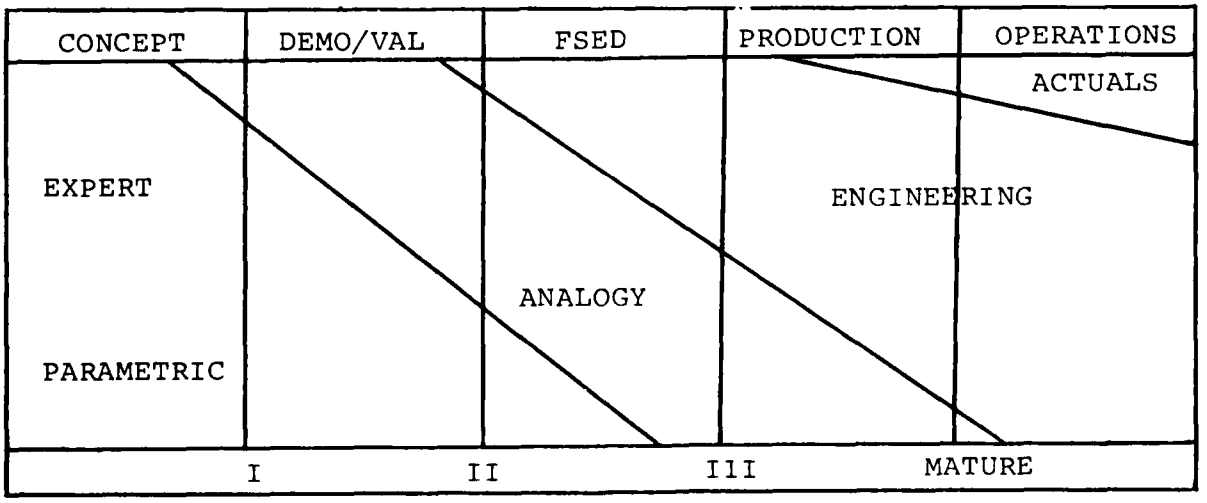
base/depot condemnations

dollars expended

others

This data passes sometimes through three data systems before it is input into VAMOSC. Those direct costs such as POL are attributed directly to the weapon system which consumed them. However, these costs such as indirect, overhead, and general and administrative are allocated to the weapon system using an allocation algorithm. These algorithms are developed using the above activity ratios. They are used to absorb the general dollars expended in our accounting system.

One of the primary uses of VAMOSC is in the cost estimation of the O&S portion of the Life Cycle Cost (LCC) of a new weapon system. There are several methods that can be used in this process; expert, parametric, analogy, and engineering. These estimation techniques are appropriate during different portions of the DSARC process as shown below with some overlap.



(2:3-8)

During the Conceptualization phase, expert and parametric estimation techniques are most appropriate because the design of the weapons system is fluid. The expert method solicits opinion from individuals acknowledged to be proficient in the area under investigation. Parametric estimation uses various mathematical processes such as regression analysis to develop a Cost Estimating Relationship (CER). A CER is a mathematical equation that relates one or more characteristics of an item to an element of cost.

During the demonstration/validation phase of the DSARC process, the design of the weapons system is finalized. At this time, analogy models become more appropriate. The analogy technique first identifies a system, subsystem, or component currently in the inventory that is similar in design/operation to the proposed new unit. The cost of the new system is developed by taking the O&S cost of the old system and adjusting it to account for differences between the two systems.

The engineering estimate techniques become useful during the Full Scale Engineering Development portion of the process. The technique uses actual cost data produced by the prototype weapon system. Engineering estimation is a bottoms-up approach that attempts to determine the actual cost that occurs in a realistic situation using actual prototype or production systems. Finally actual cost data from deployed systems is available from VAMOSC (2)..

The technique that we will use to demonstrate the use of VAMOSC is analogy estimation. As explained earlier, the analogy estimate assumes a similarity between a deployed system or portion of it and a proposed one. This comparison technique has the advantage of greater accuracy, than does the use of CERs or expert opinion, because the analogy estimate is more appropriate as the weapon system design becomes firm. Negative aspects of the analogy estimate are its laborious procedure to build up estimates of each part of the new system and a difficulty in reaching a consensus of opinion in the similarity between old and new systems.

For the analogy estimate demonstation, I will assume that we are estimating the then-year O&S costs of the new Next Generation Fighter (NGF). We are past Milestone I and the design is reasonably firm, but no prototypes have yet been developed. To support the example, several other assumptions need to be made. We will assume that:

a. 15% of the NGF is identical to existing systems

b. 65% of the NGF is similar to existing systems

c. 20% of the NGF is completely new technology.

We also must assume a similarity between the O&S costs of new components and existing ones.

For the 15% of the components of the NGF that are identical to existing systems, we will use the historical O&S cost for the estimate. It has been decided that the AN/ARC-164 radio will be installed in the NGF. It is also used on the F-15. We will assume identical cost because of identical operations. The O&S cost of the radio and its components can be found in the Component Support Cost System (D160B) of VAMOSC. An appropriate year or years will be selected for the radio's cost, perhaps IOC + 5 years, to show mature system operational costs. For all component costs, we must discount them back to a base year, then all costs must be normalized to the base year of the analysis. Finally, all costs will be compounded out to the Next Generation Fighter's IOC + 5 year, for example.

In the example, we have assumed that 65% of the NGF has similar systems to those already deployed. The fire control computer on the NGF is similar to that used on the F-16. Because of similar operation, we will assume similar costs. We again go to CSCS to costs of the 5 digit work unit code (WUC) and NSN O&S costs for the existing system. These costs may be adjusted depending on the degree of similarity between them. Then again, using Present Value theory, we discount, normalize, and compound them in order to have a homogeneous analysis.

A portion, estimated at 20%, of the NGF is completely new technology. In order to estimate the then year cost, parametric techniques combined with expert opinion should be employed. We may use the VAMOSC data bank to construct suitable CERs and employ them for an O&S cost estimate. They then should be cross-checked with experts in the area for reasonableness, using the Delphi method or any other estimating methodology that he is comfortable with.

To complete our example, the cost estimates must be integrated into a meaningful analysis. After the effects of inflation are allowed for, then an adjustment may be made for cost synergy. That is, the sum of the individual costs may be more than the total system. The O&S cost of a component of the new aircraft may have to be adjusted upward because the utilization of these systems in the aircraft may require more power, additional access or additional cooling.

The Air Force VAMOSC is now operational. It is described in AFR 400-31, Volumes I through IV, as follows:

Volume I - General Description of Policy & Procedure

Volume II - WSSC User Manual, DI60 data system

Volume III - C-E User Manual, DI60A data system

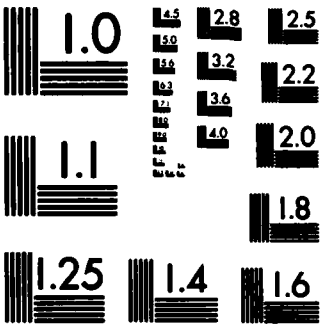
Volume IV - CSCS User Manual, DI60B data system

Output products may be requested in (1) hard copy, (2) microfiche, (3) tape, and (4) special products including custom interrogation of the data bases. WSSC & C-E are annual systems and currently have O&S costs for FY81 on approximately 100 aircraft systems and 1100 end items of communications-electronics. CSCS will be operational in September 1982 with over 300,000 NSN to WUC relationships with third quarter FY82 data available at that time. Air Force activities may order output products directly from the Office of VAMOSC (HQ AFLC/LO(VAMOSC), WPAFB, OH 45433). Other DOD activities should order first through HQ USAF/LEYM, Pentagon, Washington, D.C. 20330. Contractor

AD-A130 418 DEPARTMENT OF DEFENSE ANNUAL COST ANALYSIS SYMPOSIUM (17TH) HELD AT ARLINGTON VIRGINIA ON 12-15 SEPTEMBER 1982(U) OFFICE OF THE CHIEF OF NAVAL OPERATIONS WASHINGTON DC SEP 82 6/6

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requests should have a Air Force point of contact and current contract or Air Force sponsorship (8).

Much of the utility of the VAMOSC is dependent on the awareness of the customer community to the new resource. We have attempted to make the potential user aware of VAMOSC and have, in part, succeeded. However, we feel that if users disseminate information on VAMOSC to its organizations and encourages its use, that higher utilization of VAMOSC will occur. VAMOSC has been designed to help acquisition cost personnel and contractors develop cost models during the milestone 0 through 2 timeframes as well as other uses. We stand ready to support data requests for cost build-ups and modeling. We encourage users to utilize VAMOSC data where possible and provide input to us so that we may more fully meet your needs.

REFERENCES

1. Clements, W.P. Jr. Deputy Secretary of Defense. Memorandum, subject: Visibility and Management of Support Costs (MBO 9-2), to the Secretaries of the Military Departments, 16 October 1975.
2. May, Major Thomas E. USAF. "Operating and Support Cost Estimating: A Primer" Unpublished research report, 82-1600, Air Command and Staff College, Maxwell AFB, AL, 1982.
3. Powers, Captain Clarke W. USAF and Thomas J. Recktenwalt, "Air Force Acquisition Logistics Division: Its Creation and Role," Unpublished Air Force Institute of Technology Master's Thesis, DTIC No. AD-AO61357, Wright-Patterson AFB, Ohio, 1978.
4. Recktenwalt, Thomas J. "Visibility and Management of Operating and Support Costs, System II: Historical Perspective." Unpublished research report, DLSIE No. LD 48722A, USAF Office of VAMOSC, Wright-Patterson AFB, Ohio, 1980.
5. Recktenwalt, Thomas J. "Executive Summary for VAMOSC." Unpublished research report, DTIC NO. AD-A109308, USAF Office of VAMOSC, Wright-Patterson AFB, Ohio, 1981.
6. Recktenwalt, Thomas J. "VAMOSC Research Plan: A Plan to Measure and Control the Validity and Accuracy of VAMOSC Logic and Data Sources." Unpublished working papers, draft, USAF Office of VAMOSC, Wright-Patterson AFB, Ohio, 1982.
7. _____. Measurement and Control of Accuracy for VAMOSC II. USAF Office of VAMOSC, Wright-Patterson AFB, Ohio, 1980.
8. United States Air Force. Logistics: Visibility and Management of Operating and Support Cost Program, Policy and Procedures. AFR 400-31, Volume I. Washington:

HQ USAF, 1982.

9. United States Air Force. Logistics: Visibility and Management of Operating and Support Cost Program, Weapon Systems Support Costs (WSSC). AFR 400-31, Volume II. Washington: HQ USAF, 24 August 1982.

10. United States Air Force. Logistics: Visibility and Management of Operating and Support Cost Program, Ground Communications-Electronics (C-E). AFR 400-31, Volume III. Washington: HQ USAF, 12 August 1982.

11. United States Air Force. Logistics: Visibility and Management of Operating and Support Cost Program. Component Support Cost System (CSCS). AFR 400-31, Volume IV. Washington: HQ USAF, 6 August 1982.

12. United States Air Force. Acquisition Management: Integrated Logistics Support (ILS) Program. AFR 800-8. Washington: HQ USAF, 7 February 1980.

13. U.S. Department of Defense. OSD Cost Analysis Improvement Group (PA&E). DODD 5000.4. Washington: Government Printing Office, 30 October 1980.

14. U.S. Department of Defense. Design to Cost (USRDE). DODD 5000.28. Washington: Government Printing Office, 23 May 1975.

15. U.S. Department of Defense. Acquisition and Management of Integrated Logistics Support for Systems and Equipment (MRA&L). DODD 5000.39. Washington: Government Printing Office, July 1982 (Draft).

16. U.S. Department of Defense. Aircraft Operating and Support Cost Development Guide. Cost Analysis Improvement Group (PA&E). Unpublished guidance document, Washington, 15 April 1980.

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